CHANNEL EVOLUTION OF THE HATCHIE RIVER NEAR THE U.S. HIGHWAY 51 CROSSING IN LAUDERDALE AND TIPTON COUNTIES, WEST TENNESSEE

by Bradley A. Bryan

U. S. GEOLOGICAL SURVEY

Open-File Report 89-598

science for a changing world

Prepared in cooperation with the

TENNESSEE DEPARTMENT OF TRANSPORTATION and the

U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

Nashville, Tennessee

1989

CHANNEL EVOLUTION OF THE HATCHIE RIVER NEAR THE U.S. HIGHWAY 51 CROSSING IN LAUDERDALE AND TIPTON COUNTIES, WEST TENNESSEE

U. S. GEOLOGICAL SURVEY

Open-File Report 89-598

Prepared in cooperation with the

TENNESSEE DEPARTMENT OF TRANSPORTATION and the

U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
A-413 Federal Building
U.S. Courthouse
Nashville, Tennessee 37203

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Building 810
Box 24525
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For those readers who may prefer to use metric (International System) units rather than inch-pound units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot per second (ft/s)	3.048×10^{-1}	meter per second (m/s)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
foot (ft)	3.048×10^{-1}	meter (m)
square foot (ft^2)	9.29×10^{-2}	square meter (m^2)
mile (mi)	1.609	kilometer (km)
square mile (m^2)	2.590	square kilometer (km^2)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

CHANNEL EVOLUTION OF THE HATCHIE RIVER NEAR

THE U.S. HIGHWAY 51 CROSSING IN LAUDERDALE

AND TIPTON COUNTIES, WEST TENNESSEE

By Bradley A. Bryan

ABSTRACT

An investigation was conducted at the Hatchie River near the U.S. Highway 51 crossing in West Tennessee to (1) describe the channel cross-section evolution near the bridge crossing, (2) describe the evolution of velocity and discharge distributions near the bridge crossing, and (3) define streamflow duration and flood frequencies at the bridge site and compare these statistics with flows prior to the bridge collapse. The project was designed to document the collapse on April 1, 1989, of three spans of the bridge. Discharge measurements at the site available from the U.S. Army Corps of Engineers indicate that the channel was widening at a rate of 0.8 foot per year from 1931 through about 1975. The channel bed was stable at an average elevation of about 235 feet above sea level by 1975. Construction of a southbound bridge in 1974 and 1975 reduced the effective flow width of the channel from about 4,000 to about 1,000 feet. A flood during March 1975 scoured the channel bed lowering its elevation about 6 feet. Data collected by the U.S. Army Corps of Engineers from 1975 to 1981 indicate that the channel bed degraded to an elevation of about 230 feet and the widening rate increased to about 4.5 feet per year. The channel bed returned to approximately the pre-construction level of 235 feet as channel width increased. The widening rate decreased to about 1.8 feet per year based on U.S. Army Corps of Engineers data collected from 1981 through 1989. Channel geometry data indicates that recent channel morphology changes have occurred at the toe of the right bank, and have resulted in continued bank undercutting and bank

failure. Cross-section geometry and flow-velocity distributions determined from U.S. Geological Survey discharge measurements made between April 6 and 10, 1989, indicate that there is a high-flow meander pattern through this river reach. The bridges are located at or near the apparent meander inflection.

INTRODUCTION

On April 1,-1989, bents 70 and 71 of the northbound (upstream) lanes of the U.S. Highway 51 dual bridges over the Hatchie River in West Tennessee collapsed along with three spans of roadway. Several vehicles plunged into the river resulting in eight known fatalities. The specific cause of the failure is not known. The recent collapse of other bridges such as on the Scoharie Creek in New York, April 1987, and the Great Miami River in Ohio, May 1989, has prompted concerns on the effects of fluvial processes on stream channels near major bridge sites. Hypotheses about the cause of the Hatchie River bridge failure include local scour, channel migration, and sustained high flow with resultant general scour near the bridges.

Although the effects of scour on bridge structures is an important national problem and is the subject of extensive research by federal, state, and local agencies and universities, much on the effects of scour on bridge structures is still unknown. Some of the processes that control scour of stream channels and banks in West Tennessee are described by Robbins and Simon (1983). Similar investigations at other sites are described by Yang (1979). There is a need, however, to define other factors and processes that result in the scour of piers, abutments, bents, and other structures supporting bridges. This information can be valuable in the design of new bridges and in the implementation of remedial measures at bridges undergoing scour.

The U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Transportation (TDOT) and the Federal Highway Administration (FHWA) of the U.S. Department of Transportation, is developing techniques for identifying scour-critical bridges. Data from about 3,500 bridges throughout Tennessee are being collected during phase one of the project. A second phase of the investigation is designed to collect detailed data from bridges with high potential for scour and other channel stability problems. The bridge over the Hatchie River at the Highway 51 crossing in West Tennessee is included among the sites being studied as part of the second phase of the project.

The purposes of the investigation near the Hatchie River bridge were as follows:

(1) Describe the evolution of cross section and channel characteristics near the bridges.

(2) Describe the evolution of velocity and discharge distributions near the bridges.

(3) Define streamflow duration and flood frequencies from data collected by the COE at the bridge site and compare these statistics with flows from November 1988 through March 1989 to determine how the 1989 flood season ranked with prior flood seasons.

Purpose and Scope

This report describes the fluvial processes and the extent of channel change at the bridge site as determined from historical and recent data. It also summarizes the data collected by the USGS during the investigation.

The scope of the investigation was limited to a reach of the Hatchie River from about 1,000 feet upstream to about 1,000 feet downstream of the U.S. Highway 51 bridges.

Acknowledgments

The author acknowledges the cooperation of the Memphis District of the U.S. Army Corps of Engineers for supplying historic hydrologic data and areal photographs of the site. The Corps of Engineers staff were particularly helpful in expediting the processing and availability of current data collected from a gaging station at the bridge. The Tennessee Department of Transportation furnished bridge plans, inspection reports, and provided unlimited access to the site. The author further acknowledges the technical support to this investigation provided by the National Transportation Safety Board.

DESCRIPTION OF STUDY AREA

The Hatchie River is characterized by a low channel gradient [0.0001 foot per foot (ft/ft)], extensive meandering, well vegetated banks, and a generally stable bed. It is one of the few large rivers in West Tennessee that has not been subjected to major channel modifications. Some reaches have been cleared and snagged, but there has been no large-scale dredging or straightening of the channel. Previous studies on channel evolution in West Tennessee have shown that the Hatchie River apparently is following a natural, generally un-induced cycle of channel meandering (Robbins and Simon, 1983).

The flood plain of the Hatchie River immediately upstream of the U.S. Highway 51 crossing is thickly wooded and is 7,200 feet wide between the 264-foot elevation contours. The downstream flood plain was also thickly wooded at least through 1979 (B. R. Burke, Tennessee Department of Transportation, written commun., 1989). Aerial photography from 1984 shows that the downstream right flood plain was cleared for agriculture, leaving a narrow band of trees between the highway right-of-way and the field.

The U.S. Highway 51 crossing of the Hatchie River consists of two bridges; the northbound bridge, which is 4,201 feet long, was built in 1934 and the southbound bridge, which is 999 feet long, was built in 1975 (fig. 2). At the time of the northbound bridge construction in 1934, TDOT straightened the channel to improve flow alignment through the bridge (fig. 3). Channel stabilization measures were not implemented. The river currently approaches the bridges through a 90-degree bend to the left about 1,000 feet upstream and exits the site through a 90 degree bend to the left about 1,000 feet downstream (fig. 3).

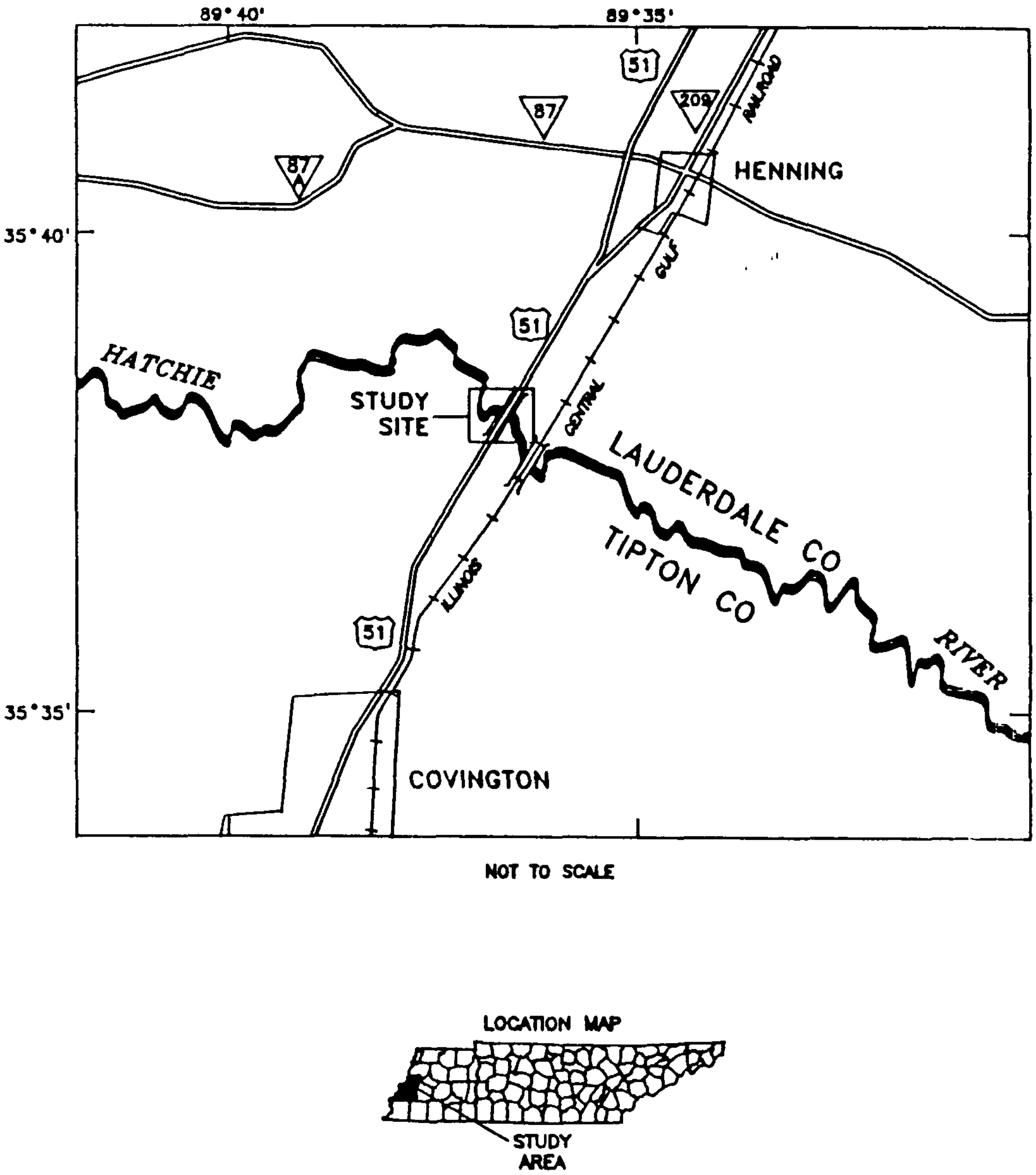
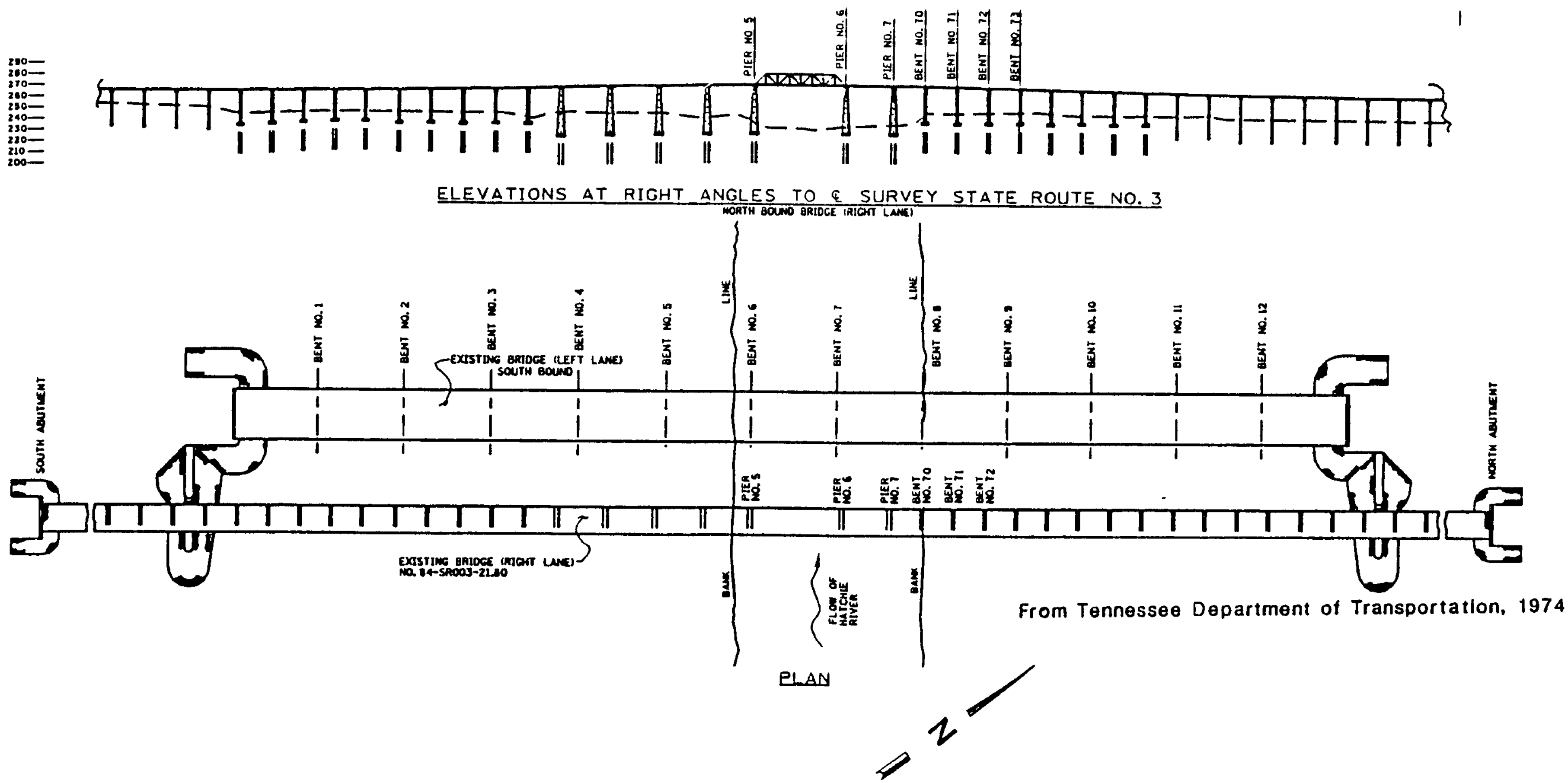
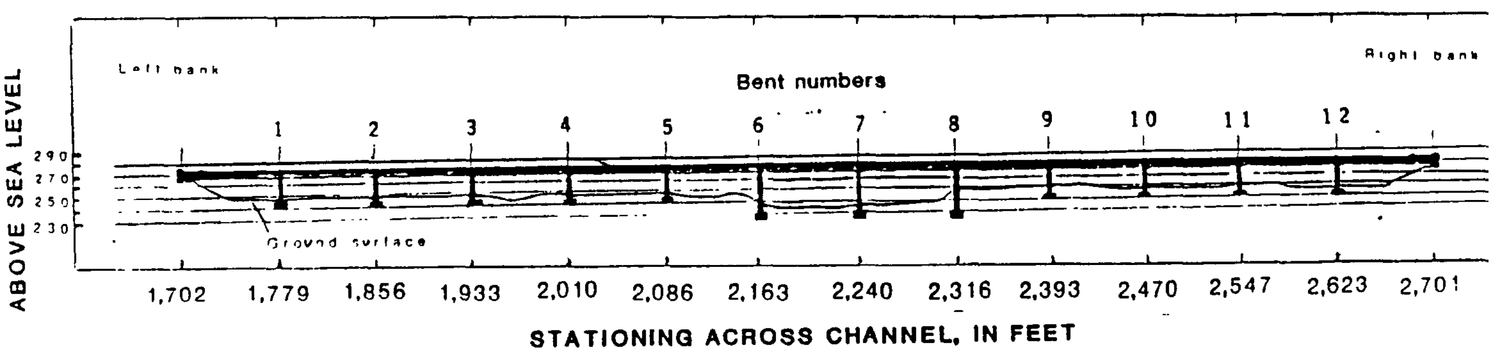


Figure 1.--Sketch showing location of the study site at the U.S. Highway 51 crossing of the Hatchie River, Lauderdale and Tipton Counties, West Tennessee.



From Tennessee Department of Transportation, 1974

Figure 2A.--U.S. Highway 51 (A) northbound bridge, and (B) southbound bridge over the Hatchie River, Lauderdale and Tipton Counties, West Tennessee.



From Tennessee Department of Transportation, 1974

Figure 2B--U.S. Highway 51 (A) northbound bridge, and (B) southbound bridge over the Hatchie River, Lauderdale and Tipton Counties, West Tennessee--Continued.

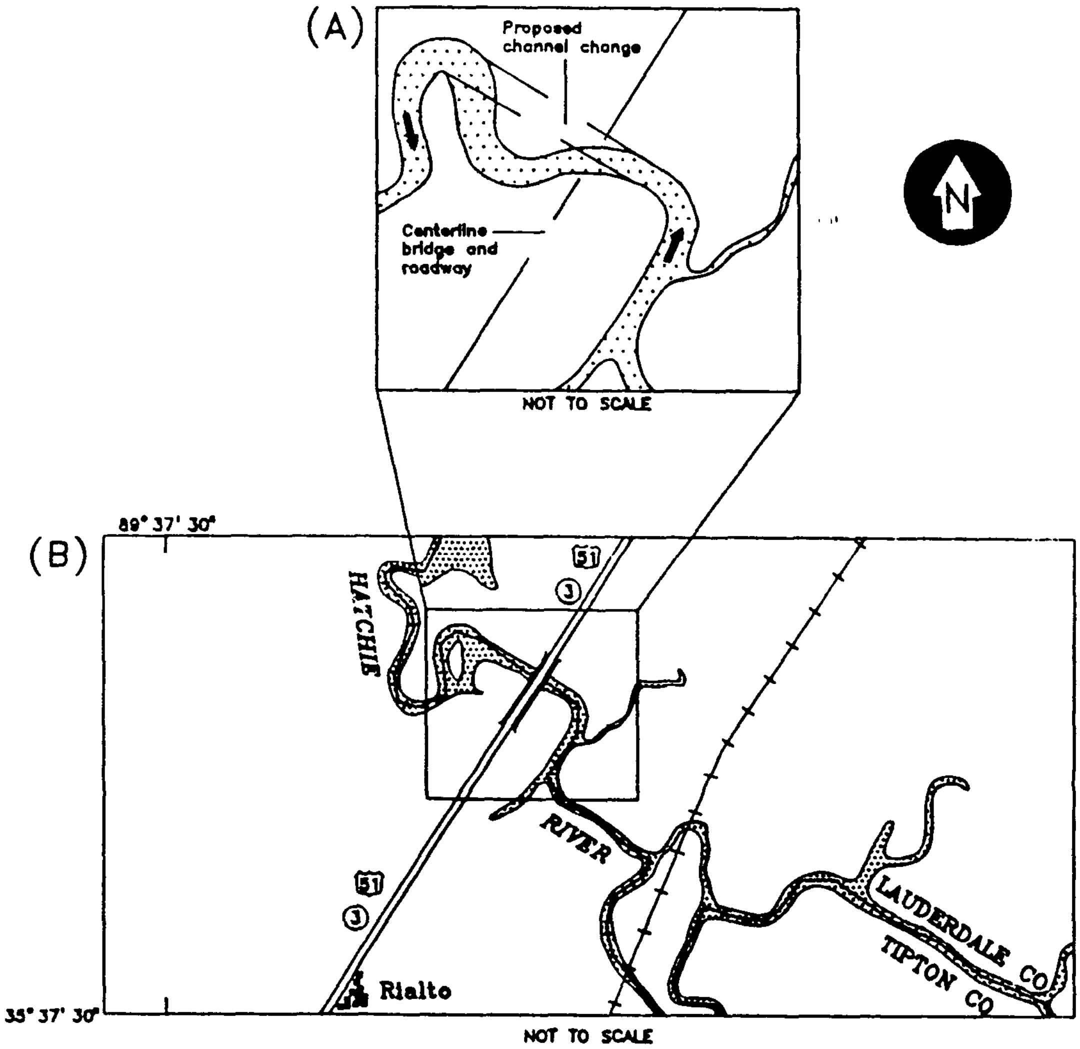


Figure 3.--U.S. Highway 51 crossing of the Hatchie River, Lauderdale and Tipton Counties, West Tennessee, showing (A) pre- and (B) post-1934 bridge construction channel alignment.

U.S. Highway 51 at this site was upgraded to four lanes and a separate bridge for southbound traffic was built from 1974 to 1975. Only a general history of bridge construction is available. Aerial photography from April 2, 1973, shows that the right-of-way for the new bridge had been cleared, but no embankment fill was in place. Approximately the same condition is shown in photographs taken on January 30, 1974. Aerial photography from October 17, 1974, shows the bridge approach embankments completed on both sides of the river. Therefore, the effect of the new southbound bridge on the channel hydraulics was probably apparent by October 1974. Hydraulic evaluation of the planned bridge by the Geological Survey indicated that a flood as large as that of 1937 (estimated to be 65,000 ft^3/s) would cause about 1 foot of backwater upstream from the bridge (W.J. Randolph, U.S. Geological Survey, written commun., 1974). Backwater due to the bridge constriction would be greatest when there is no backwater effect from the Mississippi River. However, the stage-discharge relation (especially for smaller floods) and duration of overbank floods, are greatly affected by backwater from the Mississippi River (W.J. Randolph, U.S. Geological Survey, written commun., 1974). Because of limited time and unavailability of data, a complete analysis of the effects of backwater from the Mississippi River on the flow of the Hatchie River was not made.

The following discussion of channel stability taken from Robbins and Simon (1983, p. 4,5) describes the basic geomorphologic concepts associated with the channel modification:

> "A channel is in equilibrium if it exhibits minimum rate of energy dissipation (loss) under the existing climatic, hydrologic, hydraulic, geologic, and man-made constraints (Yang, 1976). If for some reason the alluvial channel deviates from its minimum rate of energy dissipation, it will accordingly adjust its velocity, slope, roughness, geometry, and pattern of channel shifting so that energy dissipation can again be minimized (Yang and Song, 1979).

Lane (1955) describes the general relationship of the stream power concept, which can be related to minimum rate of energy dissipation, by the following expression:

$$QS \lesssim Q_s d_{50} \qquad (1)$$

where:
Q = water discharge,
S = channel slope or energy gradient,
Qs = sediment discharge, and
d50 = median particle size of bed material.

The discharge component (Q) can be expressed in a form of the continuity equation for streamflow which is:

$$Q = VA, \qquad (2)$$

where:
Q = water discharge, in cubic feet per second,
V = mean stream velocity, in feet per second, and
A = cross-sectional area, in square feet.

By assuming that streamflow is uniformly distributed throughout the cross section and that cross-sectional area (A) is unchanging, QS can be divided by the product of the water-surface width and the depth of water covering a unit bed area yielding VS (unit stream power). This implies that an increase in V and/or S will result in a proportionate increase in Qs or dso. Furthermore, if the water in a stream at a given elevation represents the potential energy input to the stream at that point, and if potential energy decreases downstream due to the loss of elevation, then the expression VS represents the total rate of energy dissipation at a given cross-section.

Energy dissipation is caused by friction from roughness along the wetted perimeter (2 x depth + width) of the channel, by friction between flow lines within the current, and by transportation of sediment and debris. Rubey (1933) estimated that roughly 97 percent of the total energy losses within a stream can be accounted for by friction. Consequently, energy utilized for transportation is very small in comparison to that dissipated by friction. If total energy (VS) is constant, then relatively slight changes in channel characteristics which affect frictional losses cause very significant changes in transporting power and consequently, channel morphology (Mackin, 1948). Change inflicted on an alluvial channel by man may very well involve tampering with both the wetted perimeter (place of energy dissipation) and the stream gradient (stream power function) such that a long period of instability can be anticipated."

Soils borings made for the 1974-75 construction project indicated that the channel bed was composed of deep sand and the banks were generally composed of silt overlyng deep sand. During this period, the channel bed was shown at an elevation of 235 feet and the silt/sand boundary was at an elevation of about 243 feet (B.R. Burke, Tennessee Department of Transportation, written commun., 1989). This indicates that the banks, although more resistant to fluvial erosion, would be subject to undercutting and mass wasting.

HYDROLOGY OF THE SITE

Flow Duration

The COE has operated a streamflow-gaging station at or near this site (Hatchie River at Rialto, Tenn.) since 1932. Daily mean discharge data were available for the 1940 through 1988 water years. Flow-duration analyses were done using data for water years 1940 through 1974 (prior to the construction of the southbound bridge), 1976 through 1988 (after the construction of the southbound bridge), and for the available period of record (1940-88). Comparison of the analyses for the three periods (table 1; fig. 4) indicates only slight differences in discharges for a given duration, except at the extremely high discharges. Based solely on gross flow-duration, the three periods could be considered hydrologically the same.

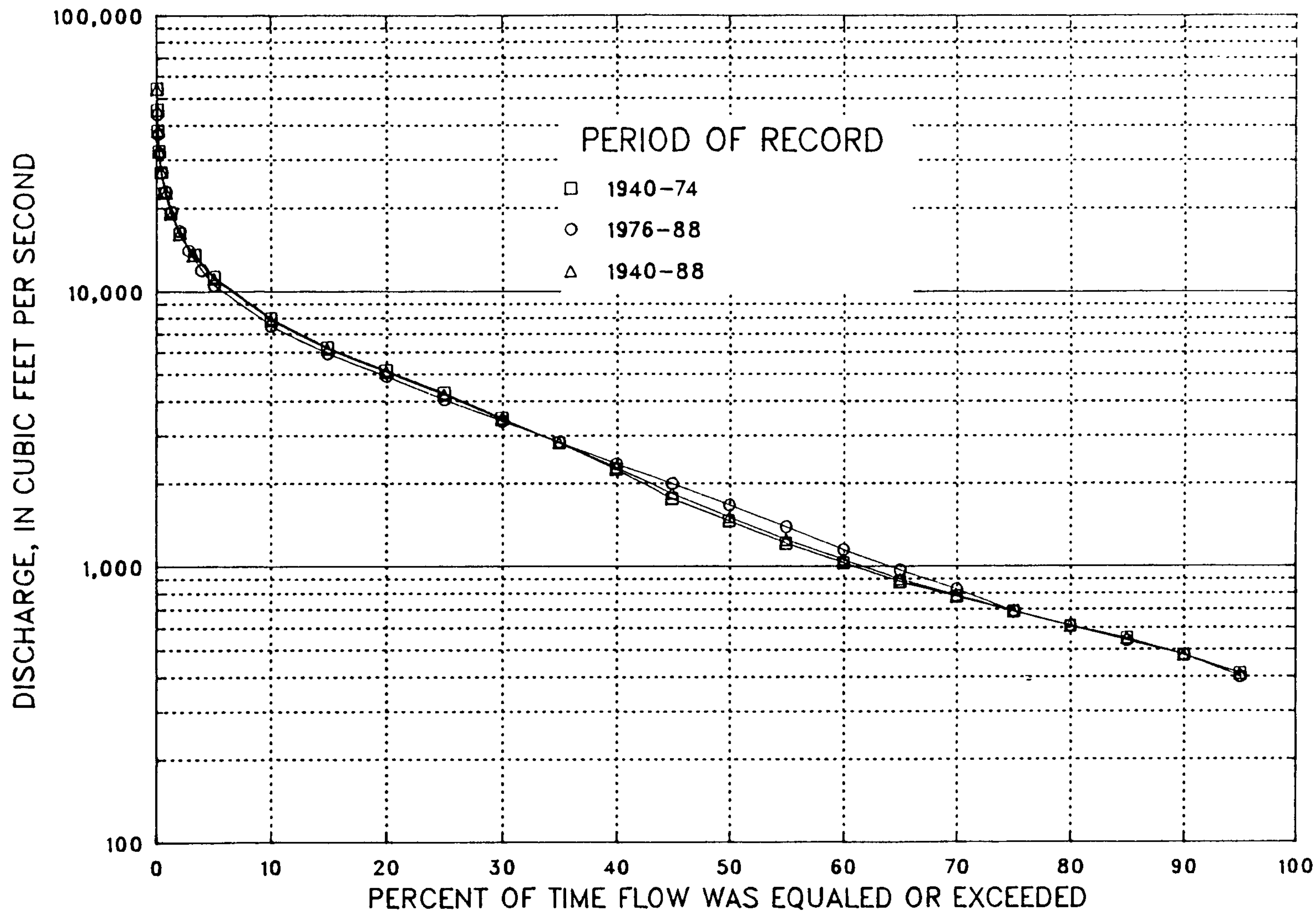


Figure 4.––Flow duration for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

Table 1.--Daily flow duration for the Hatchie River period of record, and for pre- and post-southbound bridge construction at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee

[ft^3/s = cubic feet per second]

Percent of time value equaled or exceeded	Value for period of record (1940-1988) (ft^3/s)	Value for pre-bridge period (1940-1974) (ft^3/s)	Value for post-bridge period (1976-1988) (ft^3/s)
95.0	410	410	400
90.0	480	480	480
85.0	550	550	540
80.0	610	610	610
75.0	690	690	710
70.0	790	780	830
65.0	900	880	970
60.0	1,060	1,030	1,150
55.0	1,250	1,210	1,390
50.0	1,510	1,460	1,670
45.0	1,840	1,760	2,000
40.0	2,290	2,250	2,360
35.0	2,830	2,830	2,850
30.0	3,450	3,480	3,400
25.0	4,230	4,290	4,050
20.0	5,100	5,160	4,920
15.0	6,190	6,260	5,950
10.0	7,880	7,990	7,500
5.0	11,180	11,340	10,550
3.9	---	---	12,000
3.3	---	13,600	---
3.2	13,600	---	---
2.8	---	---	14,100
2.0	16,200	16,200	16,600
1.3	19,200	---	19,500
1.2	---	19,200	---
0.8	22,800	---	23,000
0.7	---	22,800	---
0.4	27,100	27,100	27,000
0.2	32,300	32,300	31,800
0.1	38,400	38,400	37,400
0.06	---	45,600	---
0.05	45,600	---	44,000
0.02	---	54,200	---
0.01	54,200	---	---

To determine how the 1989 flood season (November 1988-March 1989) ranked within the period of record, monthly mean flows for November 1988 through March 1989 were compared with monthly mean flows for these months for each of the other years (1940-88) (table 2). The relative severity of the flood season is determined by the number of months in the 1989 flood season with discharges that rank higher than the discharges for each of the other years. Comparison of monthly mean flows (table 2) shows that at least 3 out of 5 months in the 1989 flood season had monthly mean flow values greater than each of the other years since the construction of the southbound bridge. The 1980 flood season included 3 months with monthly mean flows comparable to 1989, but only 2 months out of 5 were greater than each of the other years. Therefore, the 1989 flood season was considered the most severe since construction of the southbound bridge (1975), and generally the most severe flood season since 1973. The 1973 flood season had higher monthly mean flows (except for February) and also had the highest monthly mean flow for the period of record (March).

Table 2.--Hatchie River monthly mean flow values and ranking for flood-prone months at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee

[ND = No Data and ft^3/s = cubic feet per second]

	November		December		January		February		March	
Year	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank
1939	ND	ND	ND	ND	ND	ND	15,100	3	6,730	19
1940	497	46	634	48	903	44	3,240	34	3,940	36
1941	764	31	1,450	34	2,240	36	1,380	48	1,050	49
1942	972	25	1,480	33	2,050	37	3,660	31	7,400	17
1943	661	39	1,540	32	3,980	24	2,670	40	7,720	16
1944	521	43	639	47	1,580	39	8,090	11	6,710	20
1945	749	32	2,730	26	14,400	3	5,580	26	11,600	3
1946	8,780	2	8,420	7	18,800	1	11,800	6	7,900	13
1947	2,480	13	3,050	24	8,810	9	3,630	32	3,610	41
1948	3,140	10	2,060	29	3,800	25	16,600	1	10,300	4
1949	6,530	4	7,790	10	12,200	5	7,080	17	5,230	28
1950	1,280	21	5,350	16	15,600	2	15,400	2	7,830	14
1951	3,640	8	5,660	15	11,000	6	10,800	8	5,700	25
1952	2,170	14	7,950	9	5,870	18	8,630	10	7,930	12
1953	797	29	1,280	40	1,580	40	8,040	12	8,750	9
1954	553	42	1,130	41	6,280	16	5,700	25	3,670	38
1955	461	47	633	49	896	45	2,850	38	9,260	8
1956	708	36	975	43	1,530	41	14,700	4	4,750	33
1957	435	48	1,010	42	2,410	33	13,700	5	4,510	34
1958	9,190	1	8,150	8	3,450	27	3,000	36	3,640	40
1959	1,350	20	1,360	37	3,420	28	7,170	15	3,650	39
1960	911	27	3,680	22	4,530	22	4,730	27	6,170	24
1961	973	24	1,350	38	2,580	31	3,850	29	10,000	7
1962	1,660	16	8,880	4	8,890	8	7,530	13	10,200	5
1963	674	38	708	45	787	47	1,400	47	5,270	26
1964	508	45	841	44	1,660	38	1,970	43	7,120	18
1965	909	28	6,670	13	6,420	15	7,460	14	6,320	21
1966	564	41	704	46	1,080	42	6,140	22	3,090	43

Table 2.--Hatchie River monthly mean flow values and ranking for flood-prone months at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee--Continued

	November		December		January		February		March	
Year	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank	(ft^3/s)	Rank
1967	722	34	1,630	30	2,340	34	1,710	45	4,790	31
1968	737	33	4,780	20	7,750	11	3,060	35	4,770	32
1969	719	35	5,260	17	3,190	29	6,690	19	2,240	47
1970	1,040	23	2,300	27	6,650	14	3,290	33	4,870	30
1971	936	26	1,600	31	2,760	30	6,720	18	6,200	23
1972	508	44	2,120	28	4,630	21	2,720	39	3,290	42
1973	6,930	3	10,400	3	8,490	10	10,500	9	14,100	1
1974	6,000	5	5,220	18	5,970	17	7,110	16	4,170	35
1975	ND	ND	3,480	23	ND	ND	ND	ND	ND	ND
1976	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1977	1,430	17	1,290	39	2,470	32	1,940	44	10,200	6
1978	2,600	12	10,900	2	4,940	20	5,870	23	5,030	29
1979	677	37	6,960	12	6,960	13	5,720	24	7,760	15
1980	3,240	9	8,790	5	5,300	19	3,850	30	13,000	2
1981	1,410	18	1,420	36	879	46	2,410	42	1,920	48
1982	571	40	1,420	35	4,380	23	6,580	20	2,680	44
1983	787	30	11,500	1	9,340	7	6,410	21	5,230	27
1984	1,380	19	8,780	6	3,680	26	2,880	37	6,250	22
1985	4,050	7	3,970	21	ND	ND	ND	ND	3,750	37
1986	1,680	15	2,840	25	1,000	43	1,580	46	2,510	46
1987	2,600	11	6,230	14	2,310	35	2,550	41	7,970	11
1988	1,140	22	7,080	11	7,450	12	4,640	28	2,530	45
1989	4,080	6	4,870	19	13,300	4	11,700	7	8,590	10

Flood Frequency

Flood-frequency analyses using log-Pearson type-III distribution (U.S. Geological Survey, 1982) were performed using data for the period of record (1940-89) to determine how the 1989 flood-season peaks ranked with respect to previous years (tables 3 and 4; fig. 5). The magnitude of the flood peak for the 1989 flood season, 28,700 ft^3/s on January 19, 1989, was not extraordinary. This flood has a recurrence interval of about 3 years (table 3; fig. 5). Review of the daily mean discharges for January-April 1989 (table 5) shows that the highest daily mean flow for February was about 23,500 ft3/s, and that the highest daily mean flow during March was about 13,800 ft^3/s. Daily mean flow for April 1, 1989, was about 8,600 ft^3/s.

Additional analyses were performed using daily mean flow data at the bridge site. The highest daily mean flows for each of the months of November through March during the period of record were ranked in order of magnitude (table 6). The analysis shows that the 1989 flood season did not have consistently high ranking peaks. Even so, each month in the 1989 flood season had an out-of-bank flood (table 5). This fact is important in terms of channel processes at the bridge in that flood flows through the constricted reach could cause bed scour over an extended period of time.

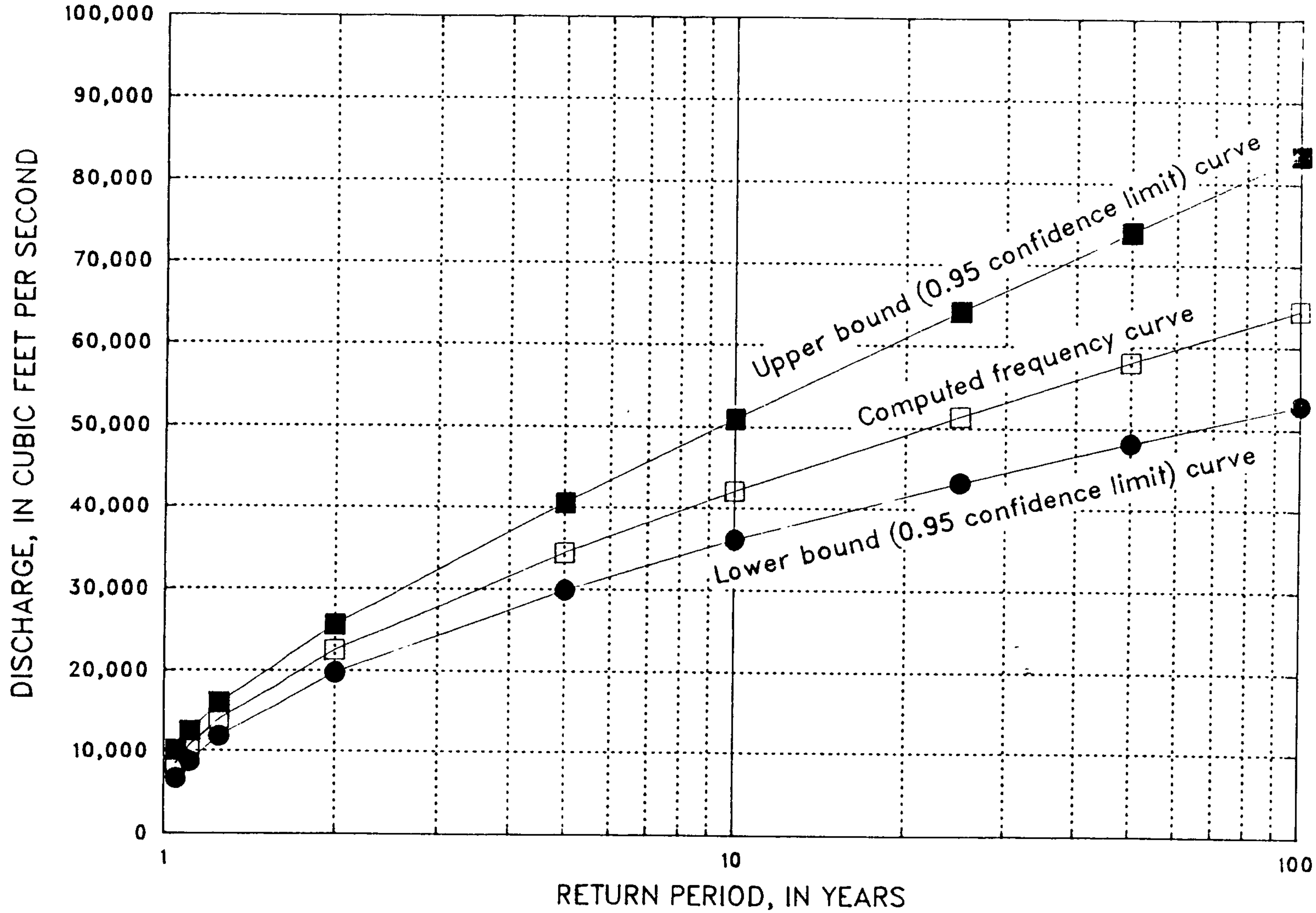


Figure 5.--Flood-frequency estimates for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

Table 3.--Flood-frequency estimates, in cubic feet per second, for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1940-89)

Recurrence interval, in years	Estimate using Water Resources Council guidelines	95-percent confidence limits for estimates using WRD[1] guidelines	
		Lower Lower	Upper Upper
1.05	8,410	6,640	10,080
1.11	10,650	8,730	12,460
1.25	13,970	11,880	16,020
2.	22,520	19,820	25,650
5.	34,430	29,990	40,600
10.	42,120	36,140	51,010
25.	51,450	43,320	64,240
50.	58,090	48,280	74,000
100.	64,450	52,960	83,560

[1]U.S. Geological Survey, 1982

Table 4.--Hatchie River annual peak flows from U.S. Army Corps of Engineers data at the U. S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee

[uv = peak flow from unit values, md = peak flow from mean daily tables; ft^3/s = cubic feet per second, and mndyyr = month, day, year]

Water year	Discharge (ft^3/s)	Code	Date mndyyr	Comment
1939	33,200	uv	020539	Oct. 1, 1938-Jan. 6,1939 missing
1940	9,420	uv	022240	
1941	3,240	uv	010241	
1942	19,900	uv	041242	
1943	21,400	uv	032043	
1944	28,300	uv	040344	
1945	34,700	uv	010745	
1946	55,700	uv	011346	
1947	12,900	uv	011147	
1948	52,300	uv	021948	
1949	25,000	uv	012949	
1950	38,500	uv	020250	
1951	28,800	uv	011551	
1952	16,600	uv	121851	
1953	26,300	uv	051853	
1954	19,500	uv	012454	
1955	28,600	uv	032955	
1956	24,500	uv	021056	
1957	30,200	uv	020857	
1958	22,800	uv	112257	
1959	15,100	uv	021759	
1960	9,180	uv	031860	
1961	17,600	uv	031561	
1962	28,000	uv	012562	
1963	9,030	uv	032063	
1964	16,000	uv	041464	
1965	39,100	uv	040665	
1966	14,800	uv	022066	

Table 4.--Hatchie River annual peak flows from U.S. Army Corps of Engineers data at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee--Continued

Water year	Discharge (ft^3/s)	Code	Date mndyyr	Comments
1967	14,500	uv	051667	
1968	16,400	uv	011768	
1969	35,300	uv	042169	
1970	22,800	uv	042870	
1971	17,600	uv	030171	
1972	7,590	uv	011772	
1973	52,000	uv	032173	
1974	30,100	uv	112873	Bridge construction
1975				Bridge construction
1976	9,770	uv	033076	Bridge construction
1977	26,700	uv	031277	
1978	38,700	uv	120677	
1979	29,600	uv	040479	
1980	45,700	uv	032480	
1981	12,600	uv	060881	
1982	15,700	md	041982	
1983	30,600	uv	010283	
1984	22,400	uv	050684	
1985				Parts of Jan. and Feb. 1985 missing
1986	5,630	md	062086	
1987	19,000	md	030787	
1988	41,700	uv	122787	
1989	28,700	md	011989	Maximum to April 1989

Table 5.--Preliminary daily mean flows, in cubic feet per second, for January through April, 1989 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee

Day	January	February	March	April
1	10,400	6,610	13,800	8,620
2	9,120	6,100	13,100	10,400
3	8,490	6,400	12,000	11,900
4	8,170	6,320	10,600	11,300
5	8,220	6,090	11,100	9,940
6	8,690	5,880	12,400	9,420
7	8,790	5,780	13,900	8,940
8	9,260	5,600	13,800	8,200
9	9,290	5,320	12,100	7,560
10	9,450	5,070	11,400	6,980
11	9,240	4,760	11,900	6,450
12	10,100	4,480	12,000	5,940
13	11,100	4,300	11,500	5,560
14	14,700	8,060	10,300	5,290
15	20,300	12,600	9,260	5,190
16	23,600	18,400	8,400	5,100
17	24,900	19,000	7,580	4,980
18	27,200	16,300	6,880	4,780
19	28,700	13,600	6,380	4,450
20	27,200	13,100	5,920	4,180
21	23,300	15,300	5,650	3,860
22	18,900	18,800	5,360	3,550
23	15,000	22,400	5,080	3,220
24	12,200	23,500	4,750	2,910
25	10,400	22,200	4,350	2,510
26	9,090	19,500	3,800	2,040
27	8,230	17,200	3,270	1,700
28	7,610	15,200	3,070	1,500
29	7,280		4,530	1,390
30	7,260		5,440	1,270
31	7,050		6,530	

Table 6.--Hatchie River maximum daily mean flows, in cubic feet per second, and ranks for the months of November through March at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee, 1939-89

[ND = No data]

Water year	November	Rank	December	Rank	January	Rank	February	Rank	March	Rank
1939	ND	--	ND	--	ND	--	33,200	3	11,700	21
1940	630	45	1,200	46	1,250	44	9,420	25	5,670	39
1941	1,270	32	3,220	32	3,240	37	2,310	47	1,460	49
1942	1,840	25	2,120	36	3,240	38	6,600	31	10,400	24
1943	1,090	36	5,130	27	9,200	19	5,400	35	21,400	6
1944	780	43	1,430	44	2,210	41	16,800	12	14,900	15
1945	1,160	34	12,200	16	34,700	2	13,600	20	20,500	7
1946	26,200	2	18,800	7	55,700	1	29,400	5	15,300	13
1947	4,860	11	5,260	25	12,900	15	5,970	33	4,360	43
1948	4,480	13	3,240	31	6,690	26	51,900	1	19,600	8
1949	23,000	3	14,400	11	23,200	8	14,400	18	13,200	18
1950	1,680	26	11,000	18	27,900	6	37,900	2	12,200	20
1951	7,690	8	10,300	22	28,600	5	17,600	10	8,880	29
1952	3,820	15	16,000	10	8,090	22	15,000	15	15,200	14
1953	1,210	33	2,180	35	2,490	39	17,100	11	14,100	16
1954	860	39	1,840	39	19,200	9	11,900	21	7,100	34
1955	508	48	1,090	47	1,280	43	5,730	34	27,600	3
1956	1,460	29	1,490	43	12,600	16	24,500	6	7,500	32
1957	546	47	1,790	40	17,400	10	29,600	4	6,150	37
1958	22,600	4	12,800	15	5,160	29	4,450	38	5,050	41
1959	2,300	21	2,040	37	6,440	27	14,700	17	6,380	36
1960	1,610	27	7,690	23	5,800	28	5,270	36	9,140	25
1961	1,450	30	1,720	41	3,610	34	8,580	27	17,600	10
1962	3,670	16	22,000	6	26,900	7	23,100	8	23,000	5
1963	852	40	972	48	995	47	2,080	48	8,910	27
1964	810	41	1,380	45	2,430	40	2,790	44	11,600	22
1965	1,590	28	13,900	12	10,100	18	19,500	9	15,900	12
1966	707	44	955	49	1,610	42	14,800	16	5,740	38
1967	1,100	35	4,240	29	3,280	36	2,520	45	7,820	31
1968	939	38	10,400	20	16,400	13	6,000	32	11,100	23
1969	2,350	20	10,400	21	4,290	32	15,100	14	3,730	46
1970	2,230	24	4,400	28	13,200	14	4,300	39	6,940	35
1971	1,330	31	3,830	30	3,590	35	15,400	13	16,900	11
1972	582	46	3,010	33	7,590	23	3,770	40	4,330	44
1973	12,200	6	17,500	8	16,700	12	13,800	19	50,000	1
1974	30,100	1	13,200	14	7,050	25	9,770	24	5,560	40
1975	ND	--	11,000	19	ND	--	ND	--	ND	--
1976	ND	--	ND	--	ND	--	ND	--	ND	--
1977	2,280	23	1,660	42	4,410	31	3,420	41	26,700	4

Table 6.--Hatchie River maximum daily mean flows, in cubic feet per second, and ranks for the months of November through March at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee, 1939-89--Continued

Water Year	November	Rank	December	Rank	January	Rank	February	Rank	March	Rank
1978	6,830	9	37,100	2	8,830	20	10,400	22	7,990	30
1979	1,080	37	22,400	5	10,200	17	10,400	23	13,000	19
1980	15,800	5	24,600	4	8,730	21	4,470	37	45,200	2
1981	2,720	19	2,540	34	1,000	46	3,290	43	2,350	48
1982	787	42	1,920	38	7,510	24	8,900	26	4,820	42
1983	2,290	22	25,100	3	30,300	3	8,460	28	8,940	26
1984	4,160	14	17,000	9	4,870	30	3,370	42	8,910	28
1985	5,770	10	5,620	24	ND	--	ND	--	7,320	33
1986	4,530	12	5,150	26	1,140	45	2,360	46	4,110	45
1987	3,630	17	13,500	13	3,740	33	7,010	30	19,000	9
1988	3,060	18	4,0400	1	17,100	11	7,720	29	3,260	47
1989	11,700	7	1,2000	17	28,700	4	23,500	7	13,900	17

Hydraulic Control

Unmodified channels in West Tennessee are relatively stable, but not static, changing slowly, even imperceptibly, over time. However, if characteristics such as cross-sectional area or flow velocity for a given discharge are altered, the effect of that discharge on channel morphology will also be altered and changes in channel morphology accelerated (equations 1 and 2). This is the concept of channel adjustment. As reach morphology changes, the hydraulic forces, sediment transport, and channel morphology will again come into balance and the rate of channel changes should decrease.

Main-channel characteristics at the bridge site were investigated through the analyses of discharge measurements made at the site. Prior to 1976, the COE made discharge measurements at the upstream (northbound) bridge. The measuring section was moved about 127 feet downstream to the new bridge (southbound) in 1976. At the time of bridge construction (1974-75), spur dikes were built on both sides of the river and were extended upstream of the northbound bridge and downstream of the southbound bridge. The entire river reach in the immediate vicinity of the two bridges was therefore exposed to similar hydraulic conditions and cross sections taken from the two measuring sections are considered to be similar.

Main-channel area appears to have gradually decreased from 1931 through 1975 (table 7; fig. 6). Top width increased from 145 feet in 1931 to about 180 feet in 1975 (table 7); an average rate of about 0.8 foot per year. During a highflow event between March 7 and March 20, 1975, the cross-section area increased by more than 600 ft^2 due to bed erosion (table 7), but channel top width remained constant. Infilling reduced main-channel capacity from 1975 through 1981 while channel top width increased by about 27 feet; an average rate of about 4.5 feet per year. Both main-channel top width and cross-section area continued to increase from 1981 to 1989 (table 7; fig. 6). Main-channel widening decreased to an average rate of 1.8 feet per year during this period, possibly indicating a stabilizing channel configuration wherein minimum energy dissipation is being approached.

The clearing of the right-downstream flood plain for agriculture was considered as a possible cause of accelerated channel widening. Aerial photography from March 16, 1979, shows that the upstream and downstream flood plain were thickly forested, while photos from 1984 show that a large part of the right, downstream flood plain had been cleared. As previously discussed, the average channel-widening rate was greater during the period from 1975-81. This is the period before and after the right bank clearing. This indicates that the flood plain clearing probablydid not cause increased channel widening.

Table 7.--Hatchie River cross-section top width and area for the main channel at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee

[ft^2 = square feet]

Date	Top width (feet)	Area (ft^2)	Location of cross section
1931	145	1,980	northbound bridge
Jan. 19, 1973	177	1,530	northbound bridge
Dec. 13, 1974	186	1,640	northbound bridge
Mar. 7, 1975	177	1,740	northbound bridge
Mar. 20, 1975	180	2,380	northbound bridge
Mar. 10, 1976	180	2,190	southbound bridge
Dec. 1, 1977	190	1,806	southbound bridge
Dec. 15, 1978	204	2,250	southbound bridge
Apr. 17, 1979	198	2,150	southbound bridge
Apr. 14, 1980	203	2,160	southbound bridge
June 9, 1981	207	2,180	southbound bridge
Dec. 17, 1982	218	2,640	southbound bridge
May 2, 1983	207	2,540	southbound bridge
Feb. 27, 1985	218	2,640	southbound bridge
Mar. 9, 1987	227	2,720	southbound bridge
Mar. 14, 1988	220	2,870	southbound bridge
Apr. 3, 1989	225	2,940	southbound bridge
Apr. 11, 1989	218	2,800	southbound bridge

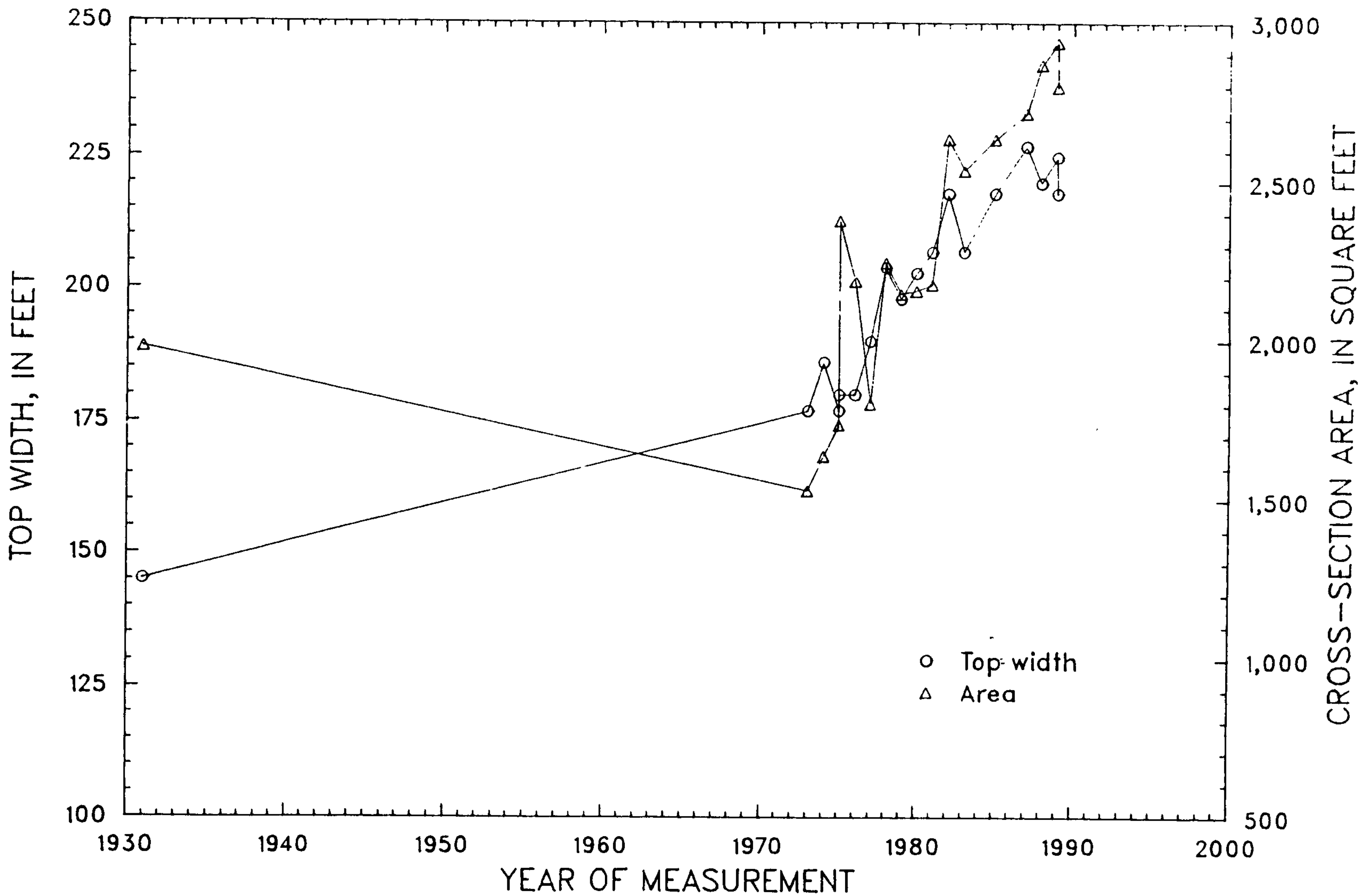


Figure 6.--Top width and cross-section area changes for the Hatchie River main channel at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

Changes in cross-section characteristics are paralleled by changes in distribution of flow velocities. The discharge measurements at the bridge site were classified by date (before and after the construction of the southbound bridge) and by approximate discharge range (table 8). The range of values and the mean of the maximum velocities in each discharge range appear to have decreased after March 1975. Only during the largest out-of-bank flows (>10,000 ft3/s), have the velocities remained about the same.

Table 8.--Descriptive statistics from Hatchie River discharge measurements made before and after construction of the southbound bridge of U.S. Highway 51, Lauderdale and Tipton Counties, West Tennessee

Prior to March 7, 1975					After March 7, 1975				
Discharge range (ft^3/s)	Maximum velocity range (ft/s)	Mean discharge (ft^3/s)	Mean maximum velocity (ft/s)	n	Discharge range (ft^3/s)	Maximum velocity range (ft/s)	Mean discharge (ft^3/s)	Mean maximum velocity (ft/s)	n
550- 940	1.53-1.60	700	1.56	4	480- 890	0.60-0.75	690	0.68	9
1,020- 2,580	1.47-2.02	1,970	1.74	5	920- 2,960	0.86-1.47	1,840	1.11	24
3,500- 9,020	2.18-3.14	5,970	2.63	11	3,320- 9,250	1.28-2.87	5,810	1.99	24
10,200-16,100	2.90-3.86	13,100	3.39	6	11,200-14,300	3.07-3.84	12,600	3.57	11

CHANNEL EVOLUTION AT THE SITE

Pre-1975 Channel Evolution

Bridge plans dated 1931 (supplied by TDOT) show that the Hatchie River was straightened to allow the bridge to across the channel at a right angle (fig. 3). The constructed channel volume was designed to approximate that of the old channel, and the channel bed elevation was set at 232.5 feet. At the time of construction, piers 5 and 6 were approximately at equal distances from the left and right banks (figs. 7, 2a).

Data from a 1944 cross section supplied by the COE (fig. 7) shows that the position of the top of left bank was relatively constant from 1931 to 1944. The channel bed had aggraded several feet to an average elevation of approximately 238 feet between piers 5 and 6, and the right top bank had retreated about 22 feet (fig. 7). These changes resulted in pier 7 being located within the main channel. Additionally, overbank accretion raised the left flood-plain elevation by 1 to 4 feet, and the right flood-plain elevation by 1 to 3 feet.

Data from a January 19, 1973, discharge measurement show that the channel continued to move to the right (fig. 7). The left flood-plain elevation increased to about 248 feet in the vicinity of the main channel and to the left of pier 5, resulting in more flow being forced toward the right bank. The main-channel bed between piers 5 and 6 had degraded to an average elevation of about 236 feet (fig. 7). The channel to the right of pier 6 had increased in area and the top of the right bank moved to about station 2320 (fig. 7); a retreat of about 20 feet since 1944.

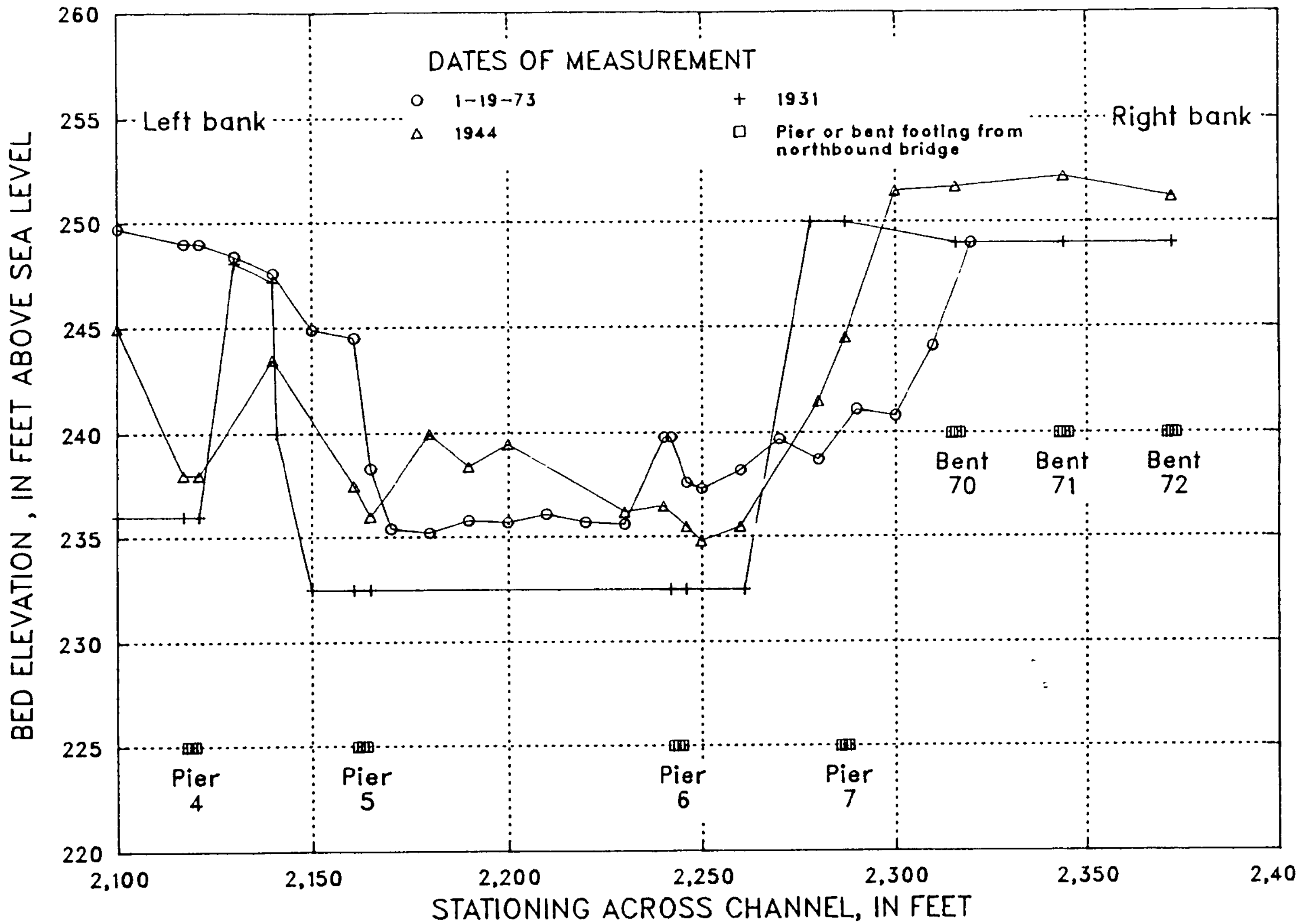


Figure 7.--Channel cross sections for 1931, 1944, and 1973 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (Cross sections taken at the northbound bridge).

During a high-flow period between March 7 and 20, 1975, the channel bed elevation at the measuring section (northbound bridge) decreased about 6 feet (fig. 8). Previous discharge measurements at the same section had not shown this type of dramatic bed-level lowering even during high discharge periods. Daily-discharge data for water year 1975 were not collected at the site due to bridge construction activities, therefore a comparison of high flow for other years was made with the Geological Survey gaging station on the Hatchie River at Bolivar, Tennessee. Comparison of tables 9 and 2 shows that high-flow ranking is consistent between the sites for years with larger flow events. Because 1975 was ranked as the third highest flow year at Bolivar, it would probably have also ranked as high at the U.S. Highway 51 bridge. Even though this indicates that the channel bed lowering during March 1975 could be related to an abnormally high flow, it should be noted that no serious channel bed lowering or channel widening occurred in conjunction with the March 1973 high flows (prior to the southbound bridge construction), which were ranked first at both discharge stations (tables 2 and 9; fig. 9).

The major change in channel-morphology control appears to have been the reduction of the bridge opening from about 4,000 feet to about 1,000 feet with the construction of the southbound-bridge embankment shortly before this episode of bed-level lowering. Discharges of 7,950 and 35,800 ft3/s were measured on March 7, 1975, and March 20, 1975, respectively. It is unlikely that these moderate peak flows would have caused the pronounced bed-level lowering measured on March 20, 1975 (fig. 8), if the hydraulic characteristics had not been significantly altered by the reduction in effective flow-width caused by the new embankment. Furthermore, severe channel-bed degradation was not evident after the March 21, 1973, peak flow of 52,000 ft3/s (fig. 9), which corresponds to about a 25-year return period (fig. 5; table 3).

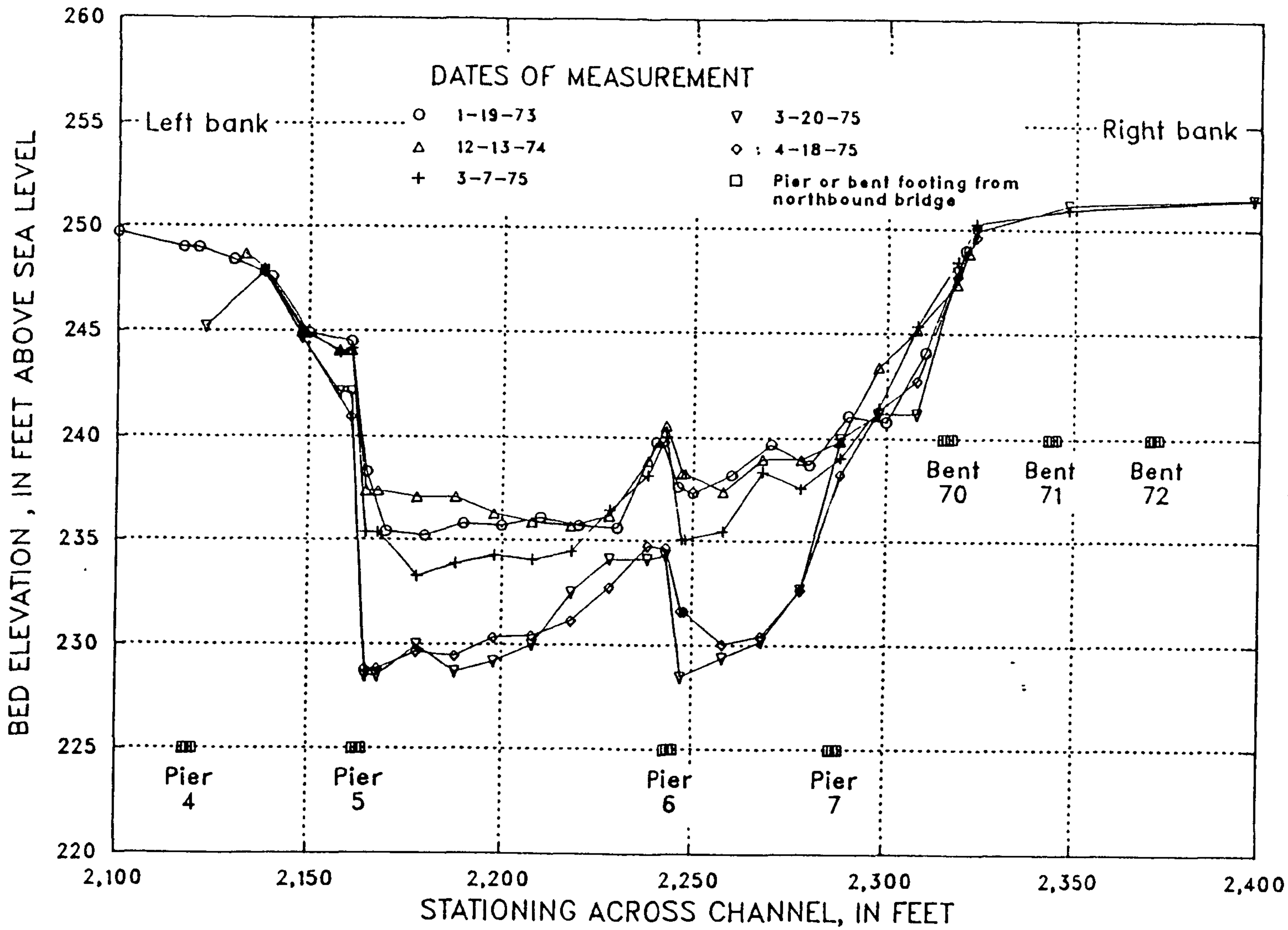


Figure 8.--Channel cross sections for 1973, 1974, and 1975 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (Cross sections taken at the northbound bridge).

Table 9.--Highest mean-discharge value, in cubic feet per second, and ranking for consecutive days for the Hatchie River at Bolivar, Tennessee

Water year	Number of consecutive days 1	Rank	30	Rank	Water year	Number of consecutive days 1	Rank	30	Rank
1930	11,800	17	4,450	26	1961	16,900	9	7,820	4
1931	7,480	32	3,610	38	1962	23,100	6	6,350	13
1932	5,030	47	2,220	52	1963	7,030	36	3,930	31
1933	16,100	10	5,800	16	1964	9,640	21	4,830	22
1934	13,000	13	5,130	19	1965	8,300	28	4,290	27
1935	12,000	16	5,740	17	1966	3,590	54	1,580	57
1936	8,900	26	3,410	39	1967	9,560	22	3,910	32
1937	2,160	58	1,540	58	1968	6,220	39	3,790	36
1938	6,380	38	3,390	41	1969	4,110	53	1,680	56
1939	7,040	35	3,820	35	1970	8,020	31	4,810	23
1940	5,400	44	3,160	42	1971	9,180	25	3,630	37
1941	2,010	59	1,070	59	1972	3,380	56	2,640	46
1942	6,570	37	3,850	34	1973	59,300	1	12,500	1
1943	11,400	18	4,850	21	1974	5,850	40	3,000	44
1944	28,700	5	6,730	8	1975	34,400	3	10,800	3
1945	10,900	19	6,610	10	1976	5,190	46	4,170	29
1946	12,400	15	4,950	20	1977	20,000	8	7,540	6
1947	4,300	50	3,070	43	1978	7,440	33	4,210	28
1948	13,100	12	6,390	12	1979	9,480	23	5,980	14
1949	16,100	11	4,540	25	1980	42,600	2	12,100	2
1950	12,700	14	6,780	7	1981	4,210	51	1,920	54
1951	8,240	29	4,580	24	1982	5,530	42	3,400	40
1952	8,670	27	6,480	11	1983	9,280	24	3,870	33
1953	10,000	20	6,640	9	1984	7,070	34	4,140	30
1954	5,540	41	1,740	55	1985	5,500	43	2,430	48
1955	31,900	4	7,760	5	1986	4,150	52	2,320	51
1956	5,220	45	2,610	47	1987	21,300	7	5,890	15
1957	4,370	49	2,860	45	1988	4,390	48	2,350	50
1958	3,410	55	2,370	49					
1959	2,770	57	2,120	53					
1960	8,200	30	5,270	18					

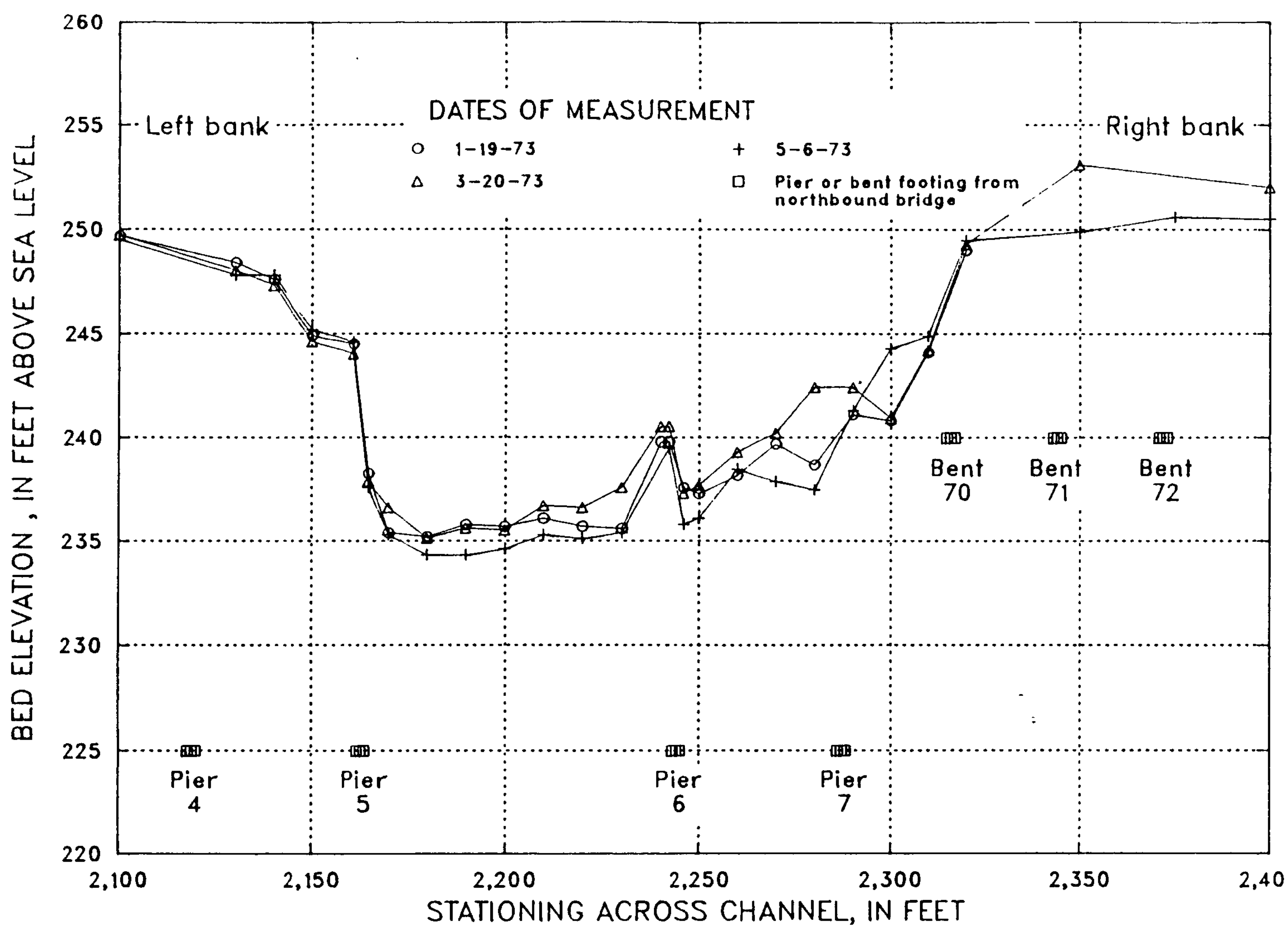


Figure 9.--Channel cross sections before and after the March 21, 1973, peak flow of the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (Cross sections taken at the northbound bridge).

Post-1975 Channel Evolution

In 1976, the COE moved their discharge-measurement section to the downstream side of the southbound bridge. Cross sections taken at the new bridge were considered to be similar to those taken at the previous measuring section located 127 feet upstream in that both measuring sections are within the contracted opening.

The January 19, 1973, cross section was used for comparison of pre- and post-degradation channel changes (figs. 10-15) because it is the earliest available cross section from the continuous-gage record. The last year of data in each figure appears in the following figure in order to provide continuity between blocks of time. By December 1977, the left two-thirds of the channel was infilled to about the old bed elevation of 235 feet, and channel widening was occurring on both banks (fig. 10). The 1980 cross section (fig. 11) shows a reshaping of the bed, but without large amounts of degradation or widening. The April 14, 1980, cross section (fig. 12) does not show any serious bed-level lowering although discharges for the month of March 1980 was one of the higher monthly mean discharges during 50 years of record (tables 2, 4, 6). The 1981 cross section shows that channel-bed elevation generally had not been lowered, but the toe of the right bank had been noticeably eroded (fig. 12).

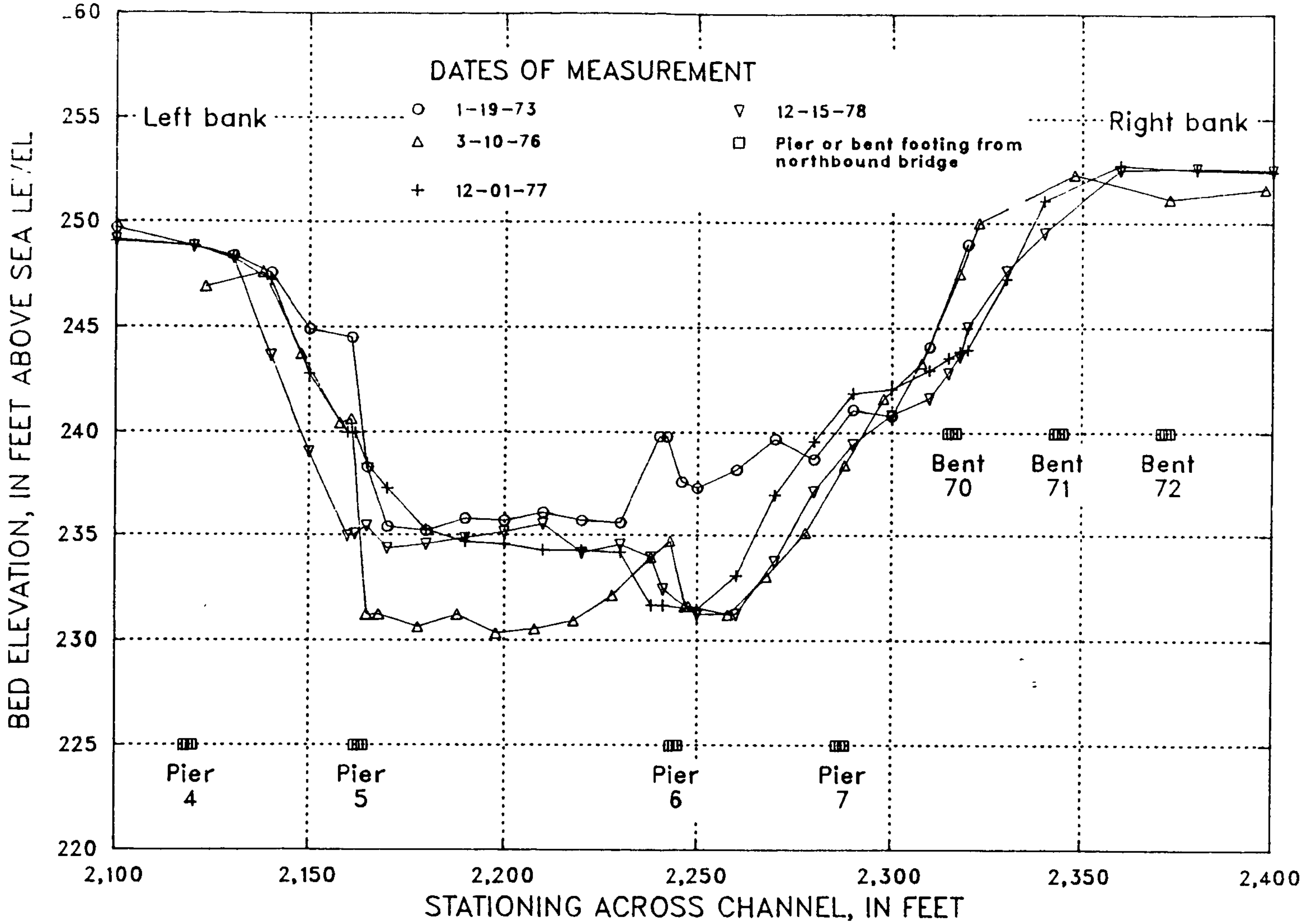


Figure 10.--Channel cross sections for 1973, 1976, 1977, and 1978 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken at the northbound bridge, others taken from the southbound bridge).

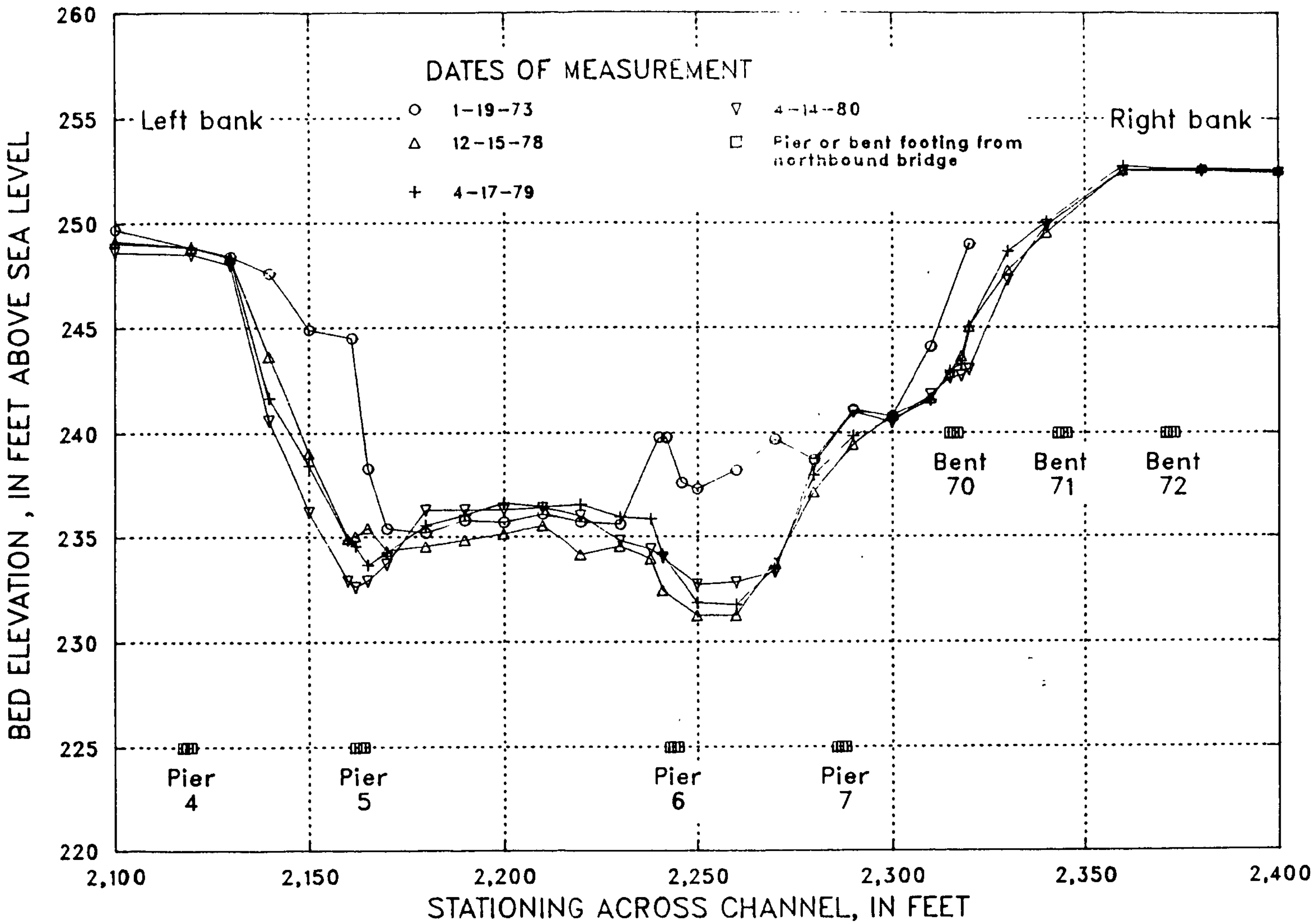


Figure 11.--Channel cross sections for 1973, 1978, 1979, and 1980 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken from the northbound bridge, others taken from the southbound bridge).

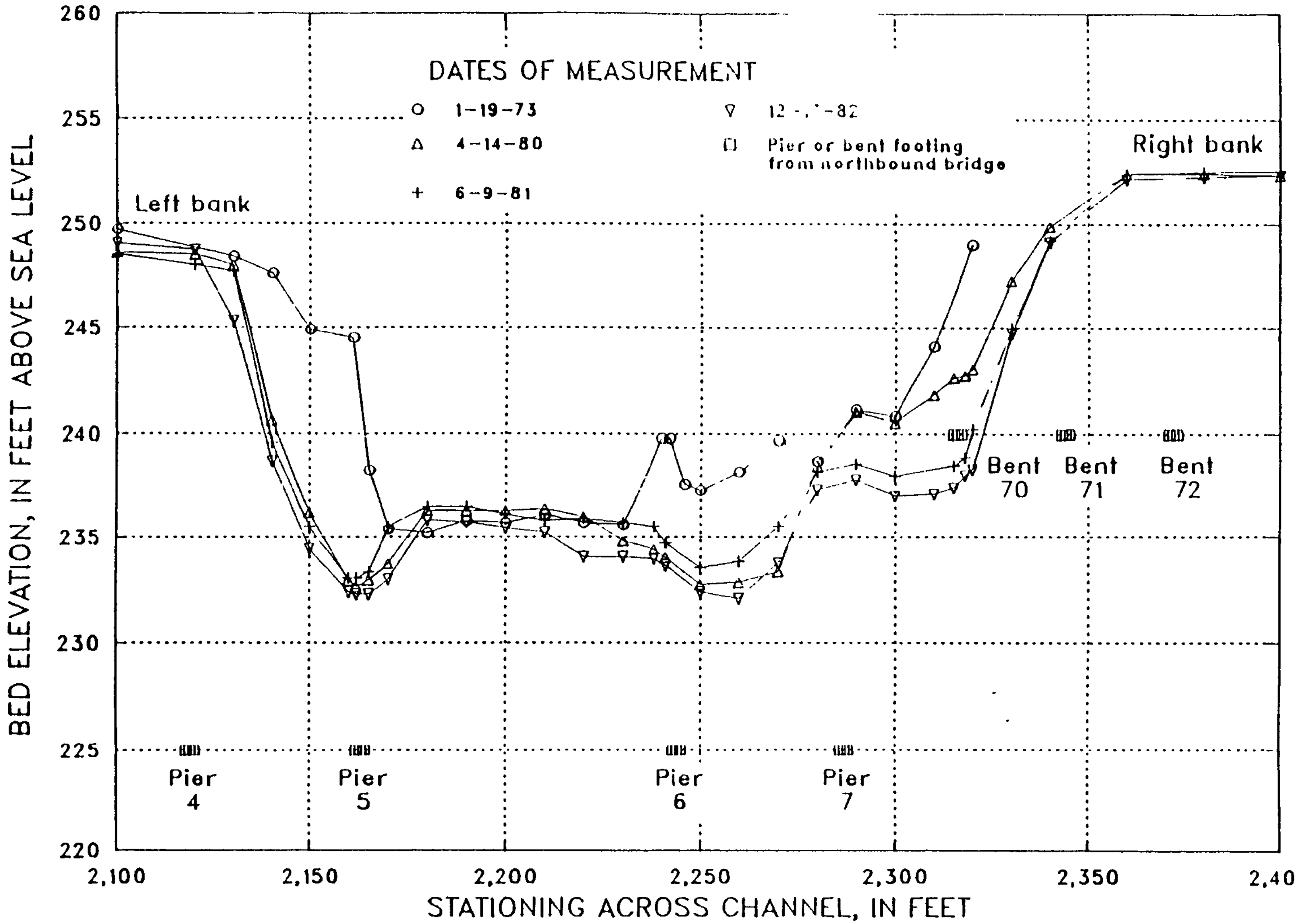


Figure 12.--Channel cross sections for 1973, 1980, 1981, and 1982 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken from the northbound bridge, all others taken from the southbound bridge).

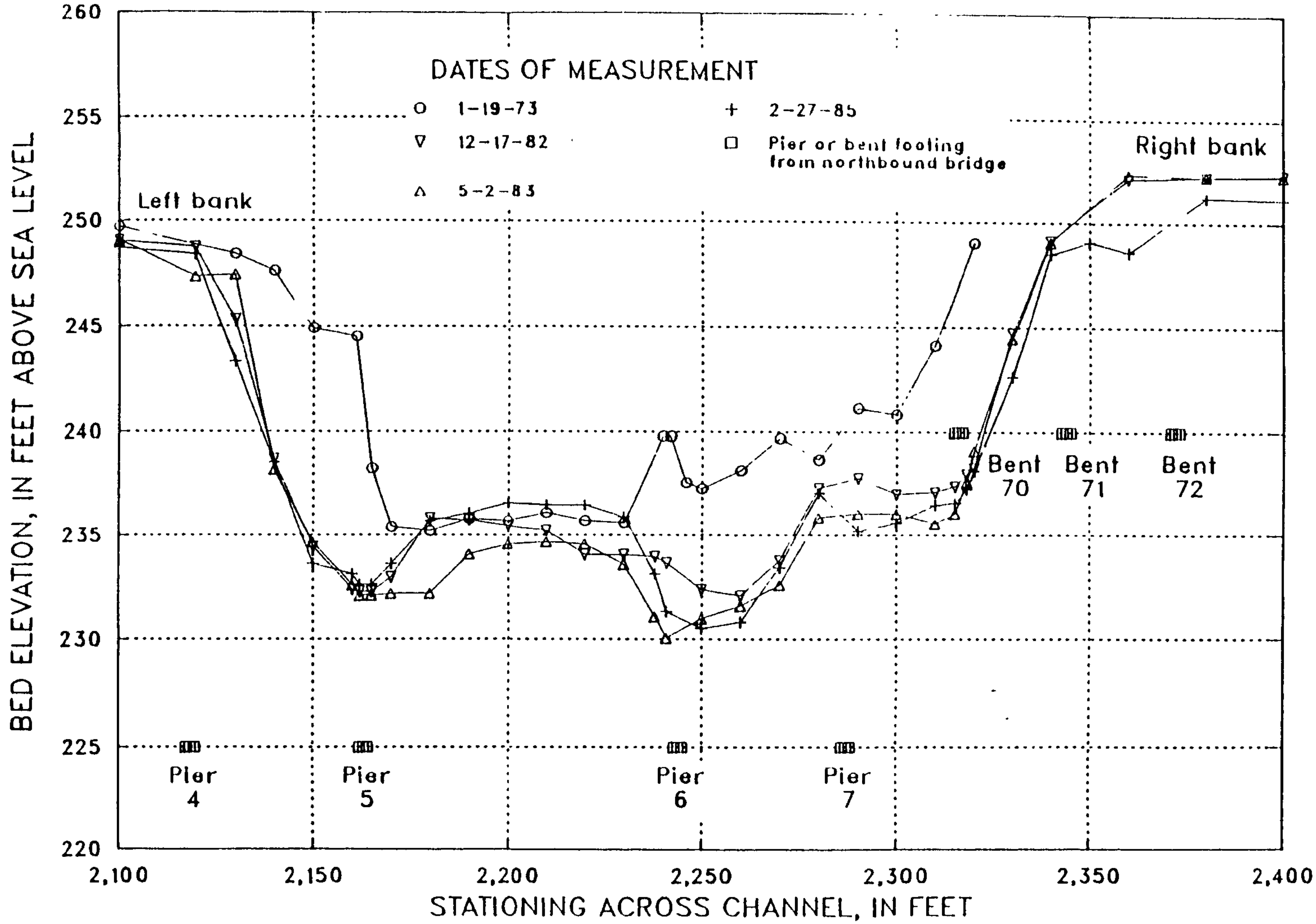


Figure 13.--Channel cross sections for 1973, 1982, 1983, and 1985 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken from the northbound bridge, all others taken from the southbound bridge).

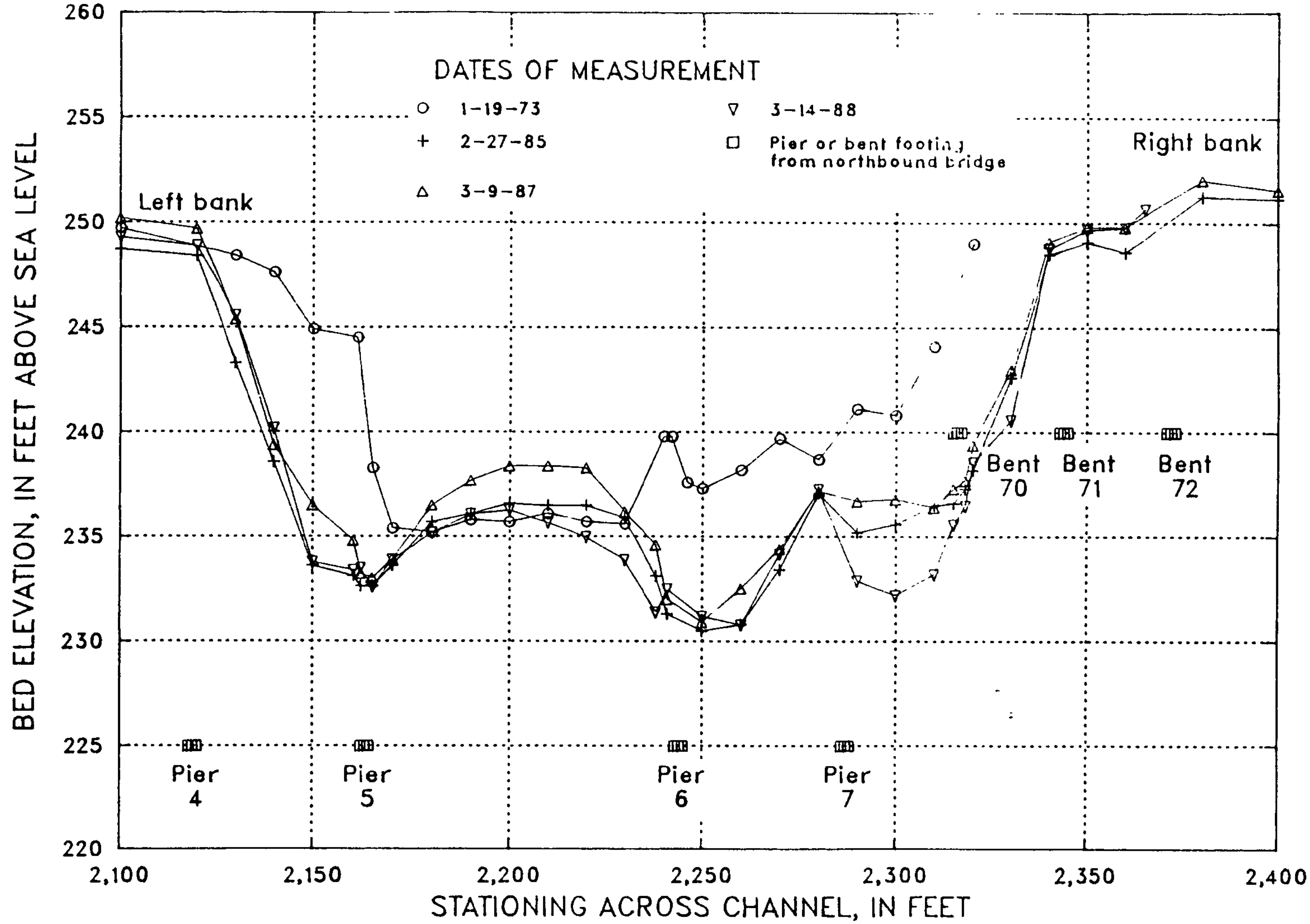


Figure 14.--Channel cross sections for 1973, 1985, 1987, and 1988 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken from the northbound bridge, all others taken from the southbound bridge).

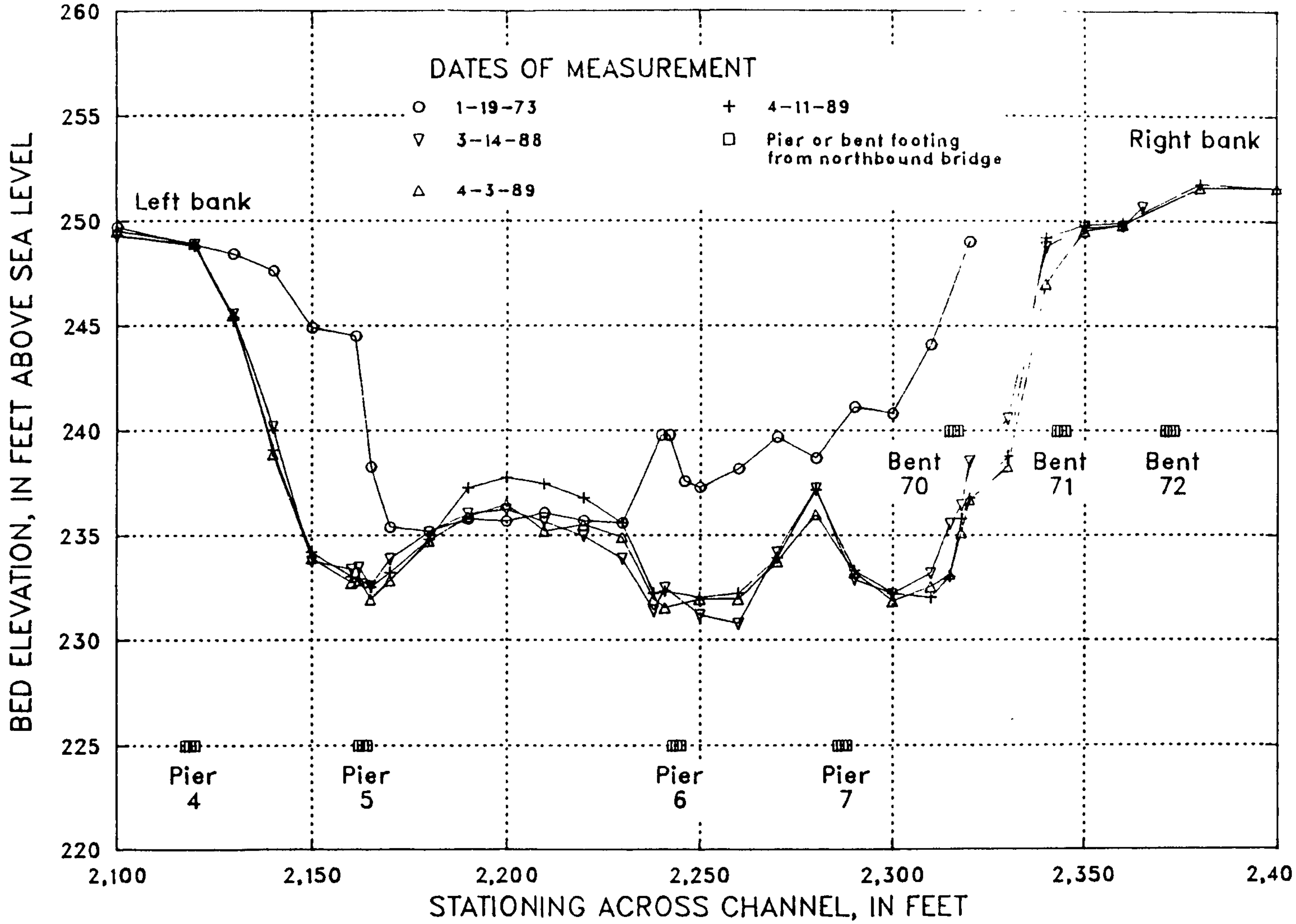


Figure 15.--Channel cross sections for 1973, 1988, and 1989 for the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee (1973 cross section taken from the northbound bridge, all others taken from the southbound bridge).

Channel widening continued through 1988. The channel bed at the toe of the right bank showed noticeable erosion both in cross sections measured in 1983 and 1985 (fig. 13). Between 1987 and 1988 the major channel change was 2 to 3 feet of further bed lowering at the toe of the right bank (fig. 14). Cross sections surveyed in April 1989 show that the pre- and post-bridge collapse channel is very similar to the 1988 cross section (fig. 15).

Study Reach Channel Morphology and Hydraulic Characteristics

To better understand channel processes at this site, velocity measurements were made at locations upstream and downstream from the bridge between April 6 and 10, 1989, while there was substantial overbank flow. Even though the measurements were made over a 5-day period and the river stage declined about 0.8 foot during this period, hydraulic characteristics within the main channel were considered to be closely related and relatively constant.

Measurements were made at cross sections (XS) 515, 190, and 45 feet upstream of the northbound bridge, at the upstream side of the northbound bridge, at the downstream side of the southbound bridge (127 feet downstream of the northbound bridge), and at the cross sections 205, 565, and 765 feet downstream of the northbound bridge. These distances are used as labels in figure 16 with downstream sections having negative values. Only the measurement at the downstream side of the southbound bridge accounted for total flow. The upstream and downstream measurements covered only the main channel because this investigation is concerned only with main-channel conditions.

Comparison of main-channel geometry (figs. 17 and 18) shows the thalweg (deepest point in the cross section) located left of mid-section at XS+515, right of mid-section at XS+190, near the right quarter section at XS+45 and near the right bank at XS-200 through XS-205. This indicates that flow is probably undercutting the right bank in this reach. The thalweg is not well defined at XS-565 and at XS-765.

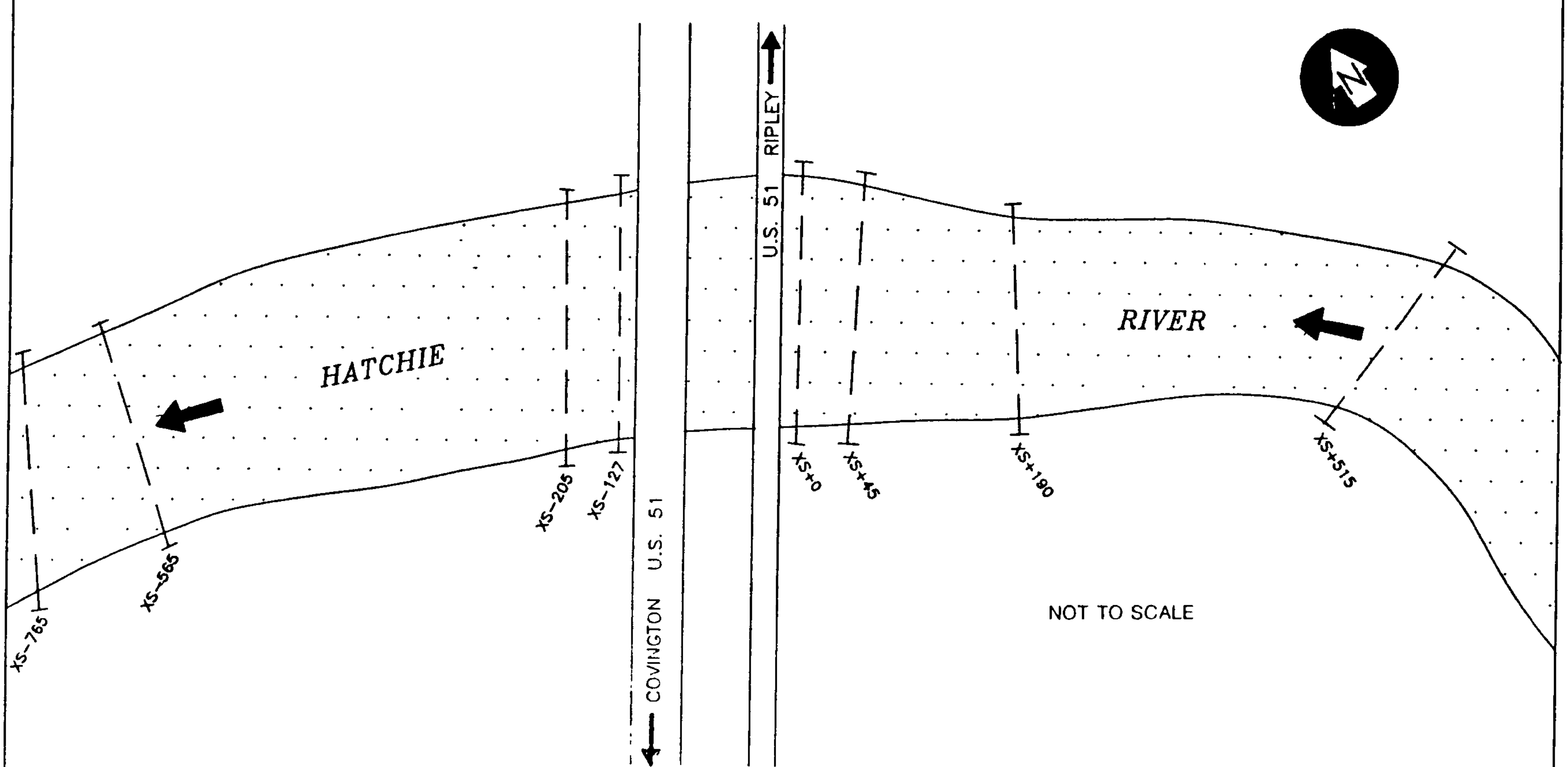


Figure 16.--Site sketch of the U.S. Highway 51 crossing of the Hatchie River, Lauderdale and Tipton Counties, West Tennessee, showing discharge measurement cross section locations.

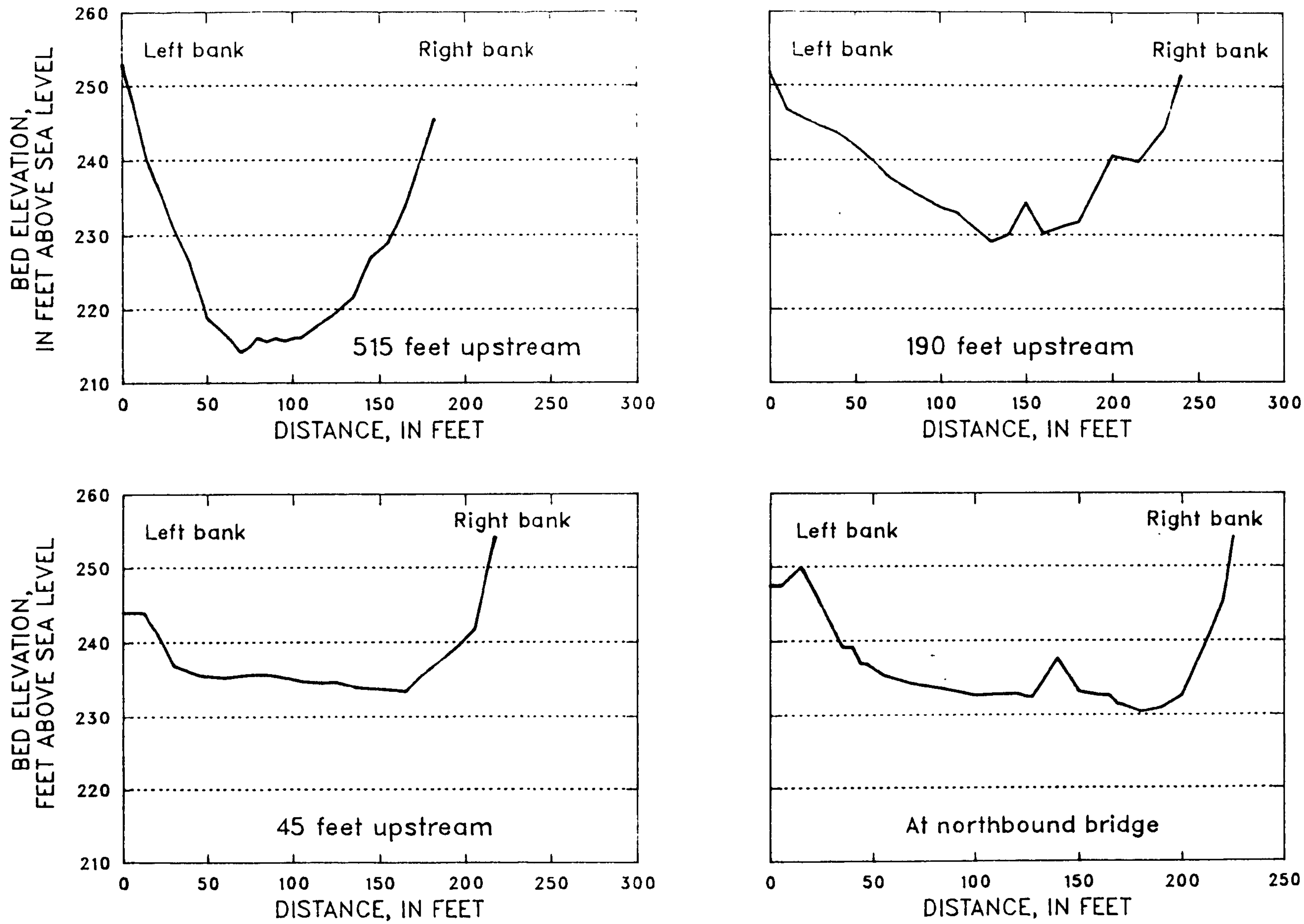


Figure 17.--April 1989 cross sections of the main channel of the Hatchie River taken upstream from the northbound bridge of U.S. Highway 51, Lauderdale and Tipton Counties, West Tennessee.

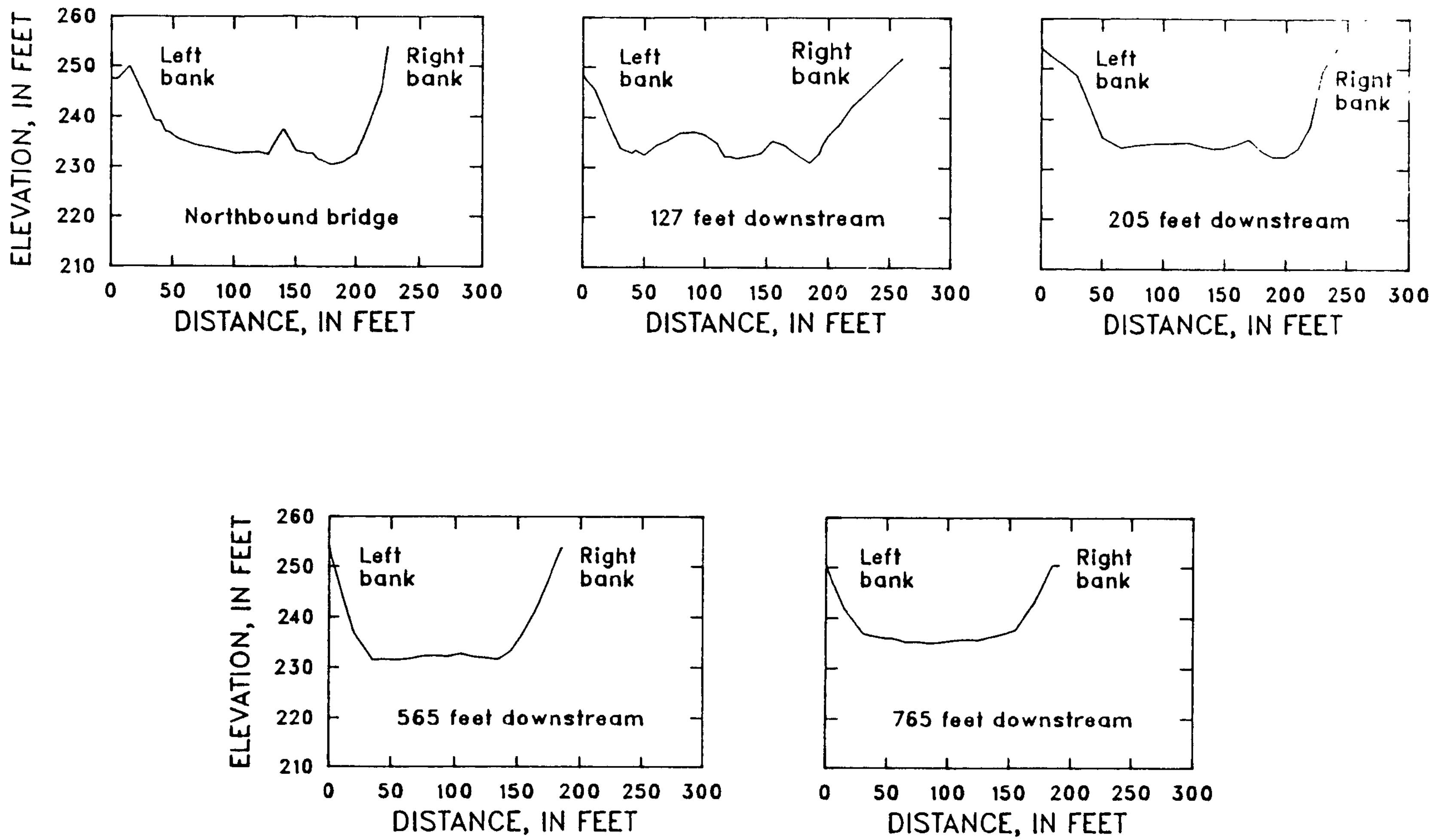


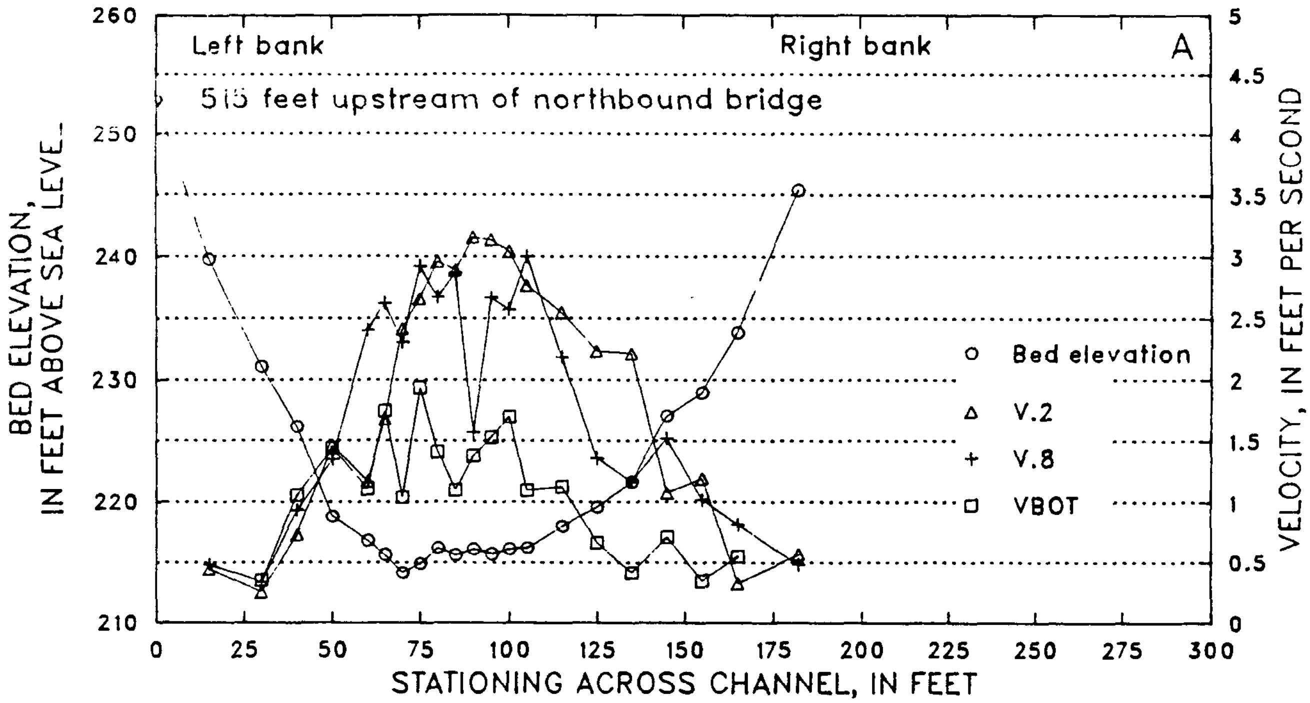
Figure 18.--April 1989 cross sections of the main channel of the Hatchie River taken downstream from the northbound bridge of U.S.highway 51, Lauderdale and Tipton Counties, West Tennessee.

Flow patterns in the study reach are complex. The upstream bend directly affects the flow pattern upstream from the bridge. The downstream bend also has a pronounced effect on the flow pattern downstream from the bridge. The flow pattern is also affected by the flow constriction caused by the bridge and by the piers and piles in the bridge.

Flow velocities at 0.2 of the depth (V.2), 0.8 of the depth (V.8), and approximately 1 foot above the bed (VBOT), for each of the cross sections measured in April 1989 are shown in figures 19-22. At XS+515, distributions for V.2 and V.8 have the same general shape, with maxima near mid-channel (fig. 19a). Maximum VBOT occurs closer to the left bank. The variability in V.8 and VBOT, and the skew of VBOT indicate the possibility of spiral flow through this section.

At XS+190 (fig. 19b), V.2, V.8, and channel shape are correlated. The VBOT distribution is peculiar and may be due to flow deflection caused by a hump in the bed at station 150. At XS+45, V.2, V.8, VBOT, and channel geometry correspond, but the velocity distributions are highly variable (fig. 20a). Again, this is probably due to the spiral flow pattern caused by the upstream bend.

At XS+0 (the upstream side of the northbound bridge), the distributions of V.2, V.8, and VBOT are similar, but maxima do not occur in the thalweg (fig. 20b). Minimum velocities on the right sides of piers indicate that flow is not parallel with the channel, which further indicates flow is skewed to the crossing probably resulting in undercutting.



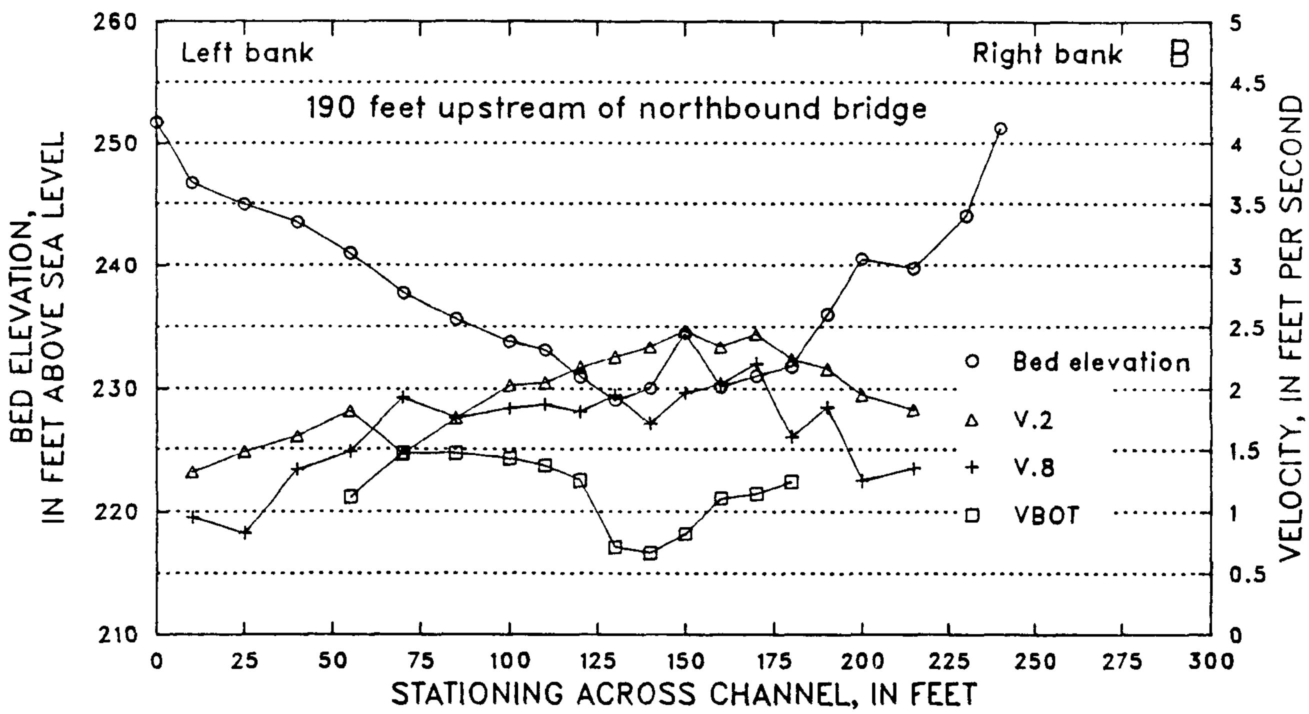


Figure 19A–B.––Measured flow velocities at .02 (V.2) and 0.8 (V.8) of the depth below water surface, at about 1 foot above the bed (VBOT), and channel configurations at cross sections 515 feet and 190 feet upstream of the northbound bridge of the main channel of the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

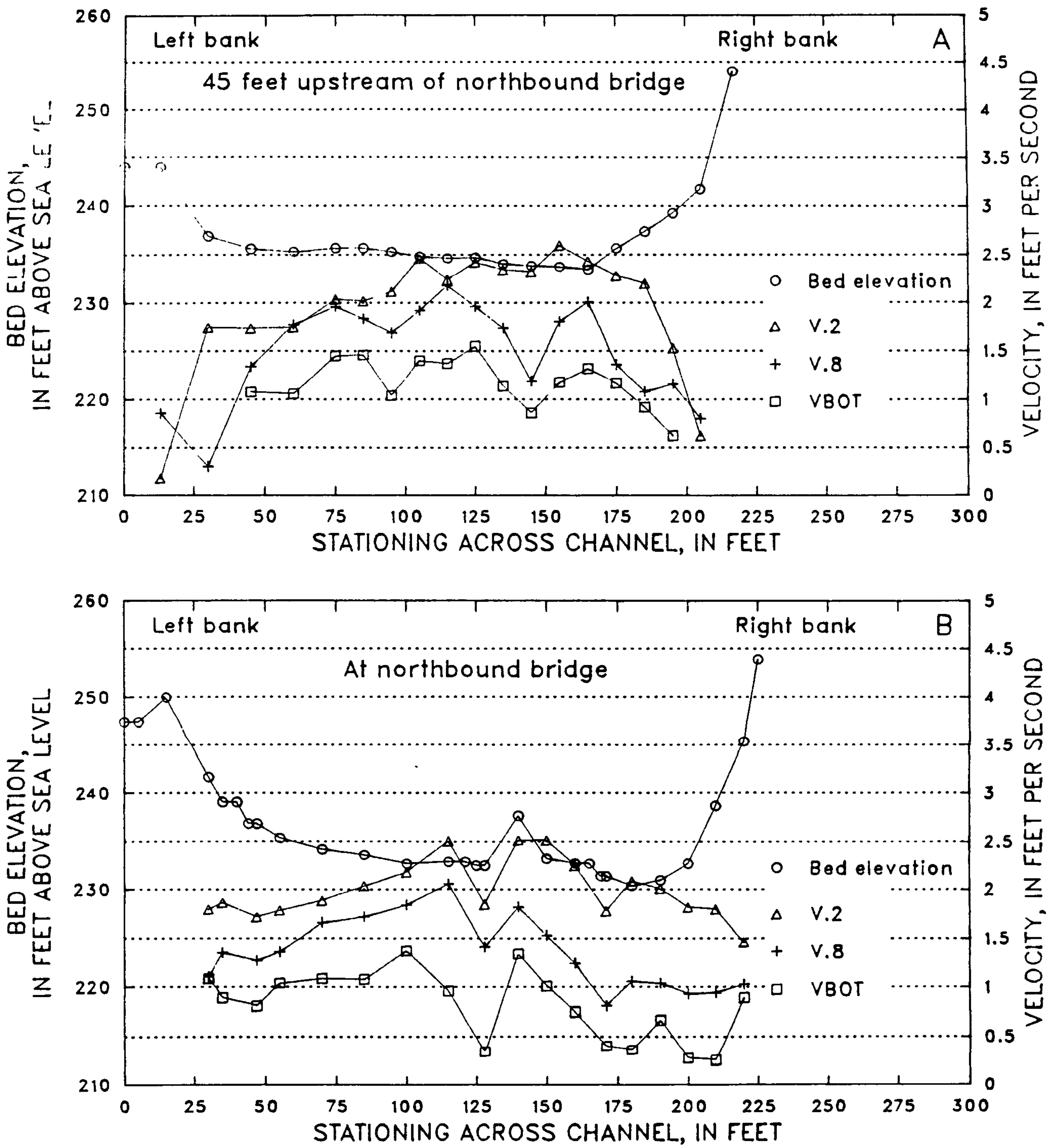


Figure 20A–B.––Measured flow velocities at .02 (V.2) and 0.8 (V.8) of the depth below water surface, at about 1 foot above the bed (VBOT), and channel configurations at cross sections 45 feet upstream of the northbound bridge and at the northbound bridge of the main channel of the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

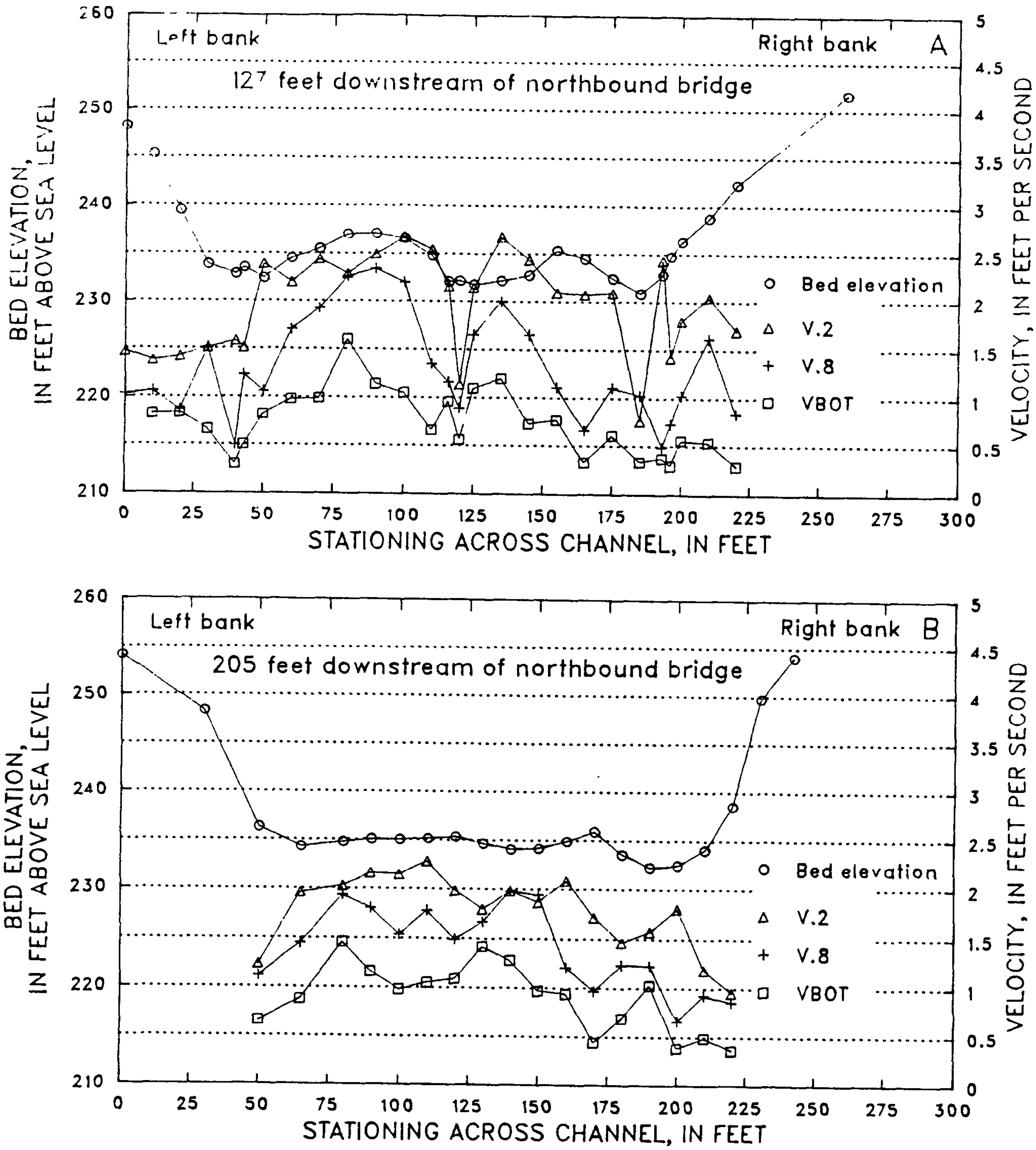


Figure 21A–B.—–Measured flow velocities at .02 (V.2) and 0.8 (V.8) of the depth below water surface, at about 1 foot above the bed (VBOT), and channel configurations at cross sections 127 feet and 205 feet downstream of the northbound bridge of the main channel of the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

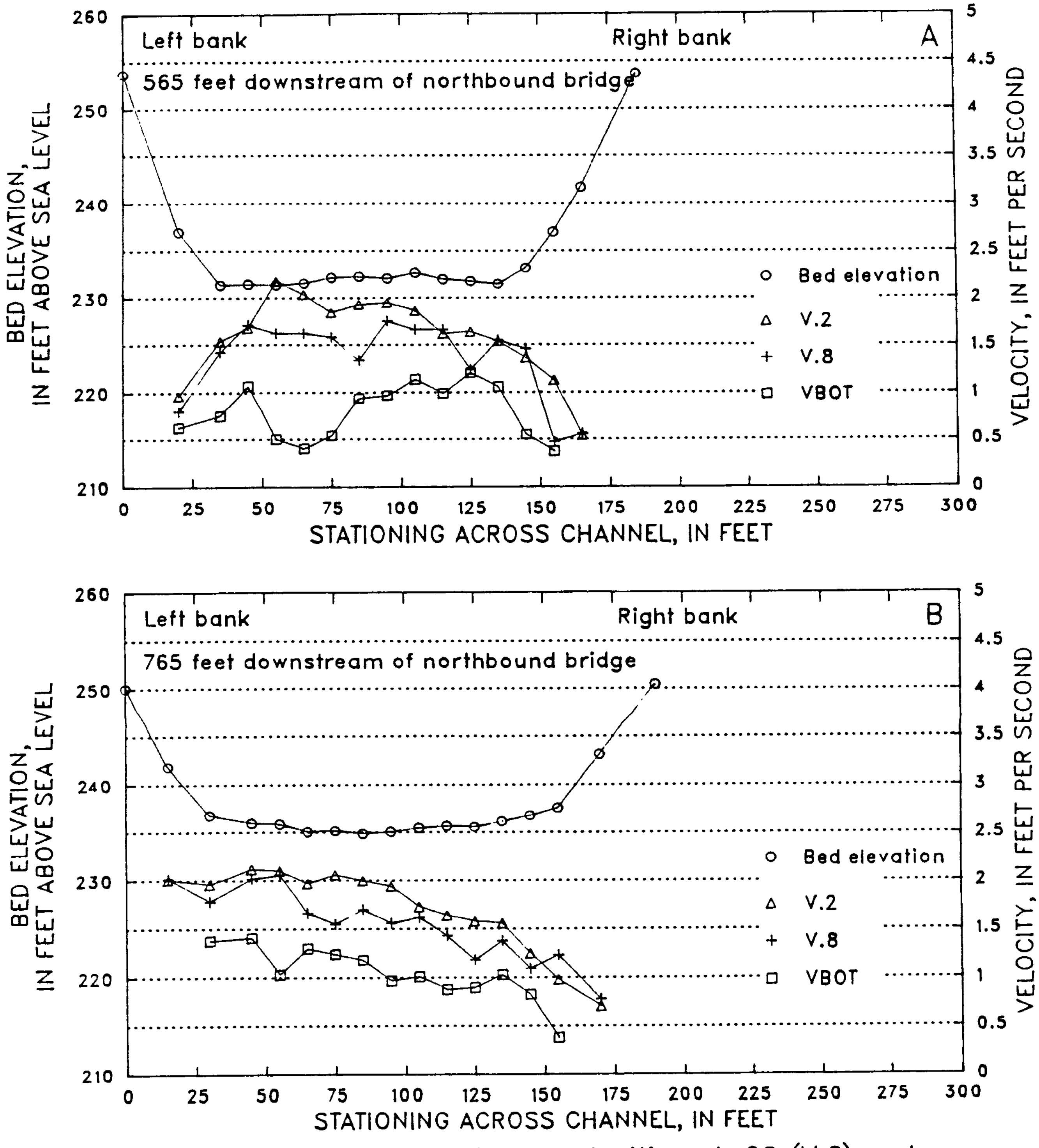


Figure 22A–B.––Measured flow velocities at .02 (V.2) and 0.8 (V.8) of the depth below water surface, at about 1 foot above the bed (VBOT), and channel configurations at cross sections 565 feet and 765 feet downstream of the northbound bridge of the main channel of the Hatchie River at the U.S. Highway 51 crossing, Lauderdale and Tipton Counties, West Tennessee.

The downstream left bend causes higher velocities to occur nearer to the left bank immediately upstream from the bend. This characteristic is clearly illustrated by the velocity pattern at XS-765 (fig. 22b), to a lesser degree at XS-565 (fig. 22a), and slightly at XS-205 (fig. 21b).

XS-205 is probably located within the transition reach where much of the flow is moving from right to left to flow around the downstream bend. Otherwise the velocities at XS-205 might be skewed more to the left. The effects of the bridge constriction and the piers and piles also may be influencing the flow pattern at XS-205.

As previously discussed, the upstream bend tends to direct the flow towards the right bank upstream from the bridge. The piers and piles change the direction of some of the flow because the flow approaches them at an angle. These factors, combined with the transition of the flow from right to left in the reach downstream from the bridge, probably induce the anomalous velocities measured at the downstream side of the southbound bridge (XS-127, fig. 31a).

The above discussions indicate that there is a high flow meander pattern through the study reach. The bridges are located at or near the apparent meander inflection point.

SUMMARY AND CONCLUSIONS

On the basis of channel cross sections obtained at the northbound bridge of U.S. Highway 51 from 1931 through 1975, the main channel of the Hatchie River was widening at an average rate of about 0.8 foot per year and by 1975 the channel bed was relatively stable at an elevation of about 236 feet. During a high-flow event between March 7 and 20, 1975, the channel bed was lowered about 6 feet (to an average elevation of about 230 feet), but channel width did not increase. Cross sections bracketing past periods of flows higher than those that caused the bed-level lowering indicate that neither abrupt bed lowering nor rapid channel widening had occurred. This indicates that channel conditions were altered at some point prior to March 1975 to such an extent that available stream power and rates of sediment transport were no longer in balance.

The sudden bed-level lowering in March 1975 occurred during the first sustained high flow after the northbound bridge opening was constricted by construction of the southbound bridge approach embankments. Channel widening accelerated after 1975 to an average rate of about 4.5 feet per year on the basis of measurements made between 1975 and 1981. Since 1981, widening rates have decreased to a current level of about 1.8 feet per year, which indicates that the channel is still adjusting but may be slowly approaching a more stable configuration.

The largest recent changes to channel shape appear to have occurred at the main channel right bank in the form of toe removal. The rate of change in channel configuration at the site of the U.S. Highway 51 crossing is slowing, but additional undercutting and bank failures could continue at this site.

REFERENCES CITED

Lane, E.W., 1955, The importance of fluvial morphology in hydraulic engineering: American Society of Civil Engineering Proceedings, 1955, v. 81, no. 745, 17 p.

Mackin, J.H., 1948, Concept of a graded river: Geological Society of America Bulletin, v. 59, p. 463-511.

Robbins, Clarence H. and Simon, Andrew, 1983, Man-induced channel adjustment in Tennessee streams: U.S. Geological Survey Water-Resources Investigations Report 82-4098, 129 p.

Rubey, W. W., 1933, Equilibrium conditions in debris-laden streams: American Geophysical Union, Transactions, p. 497-505.

U.S. Geological Survey, 1982, Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood frequency: U.S. Geological Survey Bull. 17b, Office of Water Data Coordination, Reston, Va., 28 p.

Yang, C.T., 1976, Minimum unit stream power and fluvial hydraulics: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 102, no. HY7, p. 919-934.

Yang, C.T. and Song, C.C.S., 1979, Dynamic adjustments of alluvial channels, in Rhodes, D.D. and Williams, G.P., eds., Adjustments of the fluvial system: Dubuque, Iowa, Kendall/Hunt, p. 55-67.